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INTERIMAGE EFFECTS AND THE MTF OF A COLOR REVERSAL FILM.(U)
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 79-253T ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Interimage Effects and the MTF of a COLOR Reversal Film		5. TYPE OF REPORT & PERIOD COVERED THESIS/~~DISSERTATION~~
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Joel D. Panning		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT STUDENT AT: Rochester Institute of Technology		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AFIT/NR WPAFB OH 45433		12. REPORT DATE July 1978
		13. NUMBER OF PAGES 71
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) 29 SEP 1981		
18. SUPPLEMENTARY NOTES APPROVED FOR PUBLIC RELEASE: IAW AFR 190-17 FREDRIC C. LYNCH, Major, USAF Director of Public Affairs Air Force Institute of Technology (ATC) Wright-Patterson AFB, OH 45433		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) ATTACHED		

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ABSTRACT

Interimage effects have long been recognized as a factor in the reproduction of color. Reversal materials are no exception and exhibit interimage effects which have previously been revealed through techniques using END analysis. This study presents a method for revealing the presence of interimage effects in a reversal film's Modulation Transfer Function. Utilizing filtering techniques, two dyes of a three color transparency are eliminated from the final image by exposure and development. The remaining single dye image at a specified level is then compared to the corresponding layer and image in a colorimetrically specified neutral. The edge gradient analysis method is used to calculate the Modulation Transfer Functions. MTF results indicate the desirability of using colorimetry for the specification of a visual neutral. MTF values are indicative of a significant effect on the Modulation Transfer Function by interimage effects.

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6 INTERIMAGE EFFECTS AND THE MTF

OF A COLOR REVERSAL FILM .

by

10 Joel D. Panning

9 Master's thesis

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
in the School of Photographic Arts and Sciences
in the College of Graphic Arts and Photography
of the Rochester Institute of Technology

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ABSTRACT

Interimage effects have long been recognized as a factor in the reproduction of color. Reversal materials are no exception and exhibit interimage effects which have previously been revealed through techniques using END analysis. This study presents a method for revealing the presence of interimage effects in a reversal film's Modulation Transfer Function. Utilizing filtering techniques, two dyes of a three color transparency are eliminated from the final image by exposure and development. The remaining single dye image at a specified level is then compared to the corresponding layer and image in a colorimetrically specified neutral. The edge gradient analysis method is used to calculate the Modulation Transfer Functions. MTF results indicate the desirability of using colorimetry for the specification of a visual neutral. MTF values are indicative of a significant effect on the Modulation Transfer Function by interimage effects.

ACKNOWLEDGEMENT

I wish to express my thanks to the people of the Eastman Kodak Company and the Xerox Corporation who assisted me in parts of this study. Without their help and the use of some equipment the completion of this study would have been much more difficult.

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INTRODUCTION

The reproduction capability of any photographic system can be evaluated according to specified criterion and characterized by the results. One of the quantitative measures of a film's reproduction capability is the Modulation Transfer Function (MTF). The Modulation Transfer Function is a measure of spatial frequency response or an indication of how the ratio of image contrast to object contrast varies with the spatial frequency of a predesigned object. Spatial frequency response for a given panchromatic black-and-white film is sufficiently independent of wavelength within the visible region of the spectrum. Conversely, the spatial frequency response of a color film is not independent of wavelength due to its inherent characteristics of selective absorption and layered construction. Even though the Modulation Transfer Function does not indicate how well an actual color is reproduced, it is applicable as an indicator of the spatial reproduction capability of a color film.

Reproduction capability characterized by the MTF is unique for each type of film and dependent on various factors. A significant factor in any analysis of sensitometric or image structure characteristics is the layered structure

of a color film. In color reversal materials, two of the limitations encountered in color reproduction is the undesirable absorption characteristics of the best available cyan, magenta, and yellow dyes and the light scattering properties of the layers. Colored couplers can be used as masks to eliminate the undesirable absorptions in "negative" materials but not in reversal materials intended for viewing. The absorption characteristics of processed reversal materials intended for viewing are therefore modified by what is known as interimage effects. These effects are a direct result of the combination of layered construction and processing. Thus, the amount of dye formed in one exposed layer is somewhat dependent on the presence or absence of exposure i.e. development in the other layers. The significance of these interimage effects in reversal materials intended for viewing has previously been investigated by W. T. Hanson Jr. and C. A. Horton as early as 1952.[1] They found that interimage effects were indeed significant and generally affected an improvement in color reproduction.

The photographic industry publishes characteristic and quantitative data on each commercial film that it produces. This data usually includes the MTF. Interimage effects, which modify dye densities, directly affect the contrast and ultimately the Modulation Transfer Function. Commercial criterion used in the evaluation of color MTFs utilize red, green, and blue filters to seperate the layers. The overall

visual MTF is computed from sinusoidal images traced with a microdensitometer filtered to approximate the visual luminance response of the eye. Consistent with the characteristics of layered construction and the usual layer order of blue, green, and red, the MTF of a color material is highest for the topmost or blue layer followed by the green and then the red layer. The visual MTF of the material will be approximately equal to that of the green layer. Published data on the MTF of color films varies within the industry. The characteristic MTF for some color films is published as three individual curves but usually the film is characterized by the visual curve only.

Since interimage effects in reversal materials intended for viewing have mainly been studied through observations and analysis of analytical densities, it is of interest to extend the investigation by presenting evidence of interimage effects as manifested through the Modulation Transfer Function. As a secondary objective, the relationship between the individual MTFs of the seperate dye layers and the overall visual MTF is worthy of analysis. This is of special interest because there is no ANSI standard for MTF measurement of color materials. Furthermore, the method of edge analysis is applicable since this allows correlation to practical application of color reversal aerial camera films. Results and analysis can be directed towards the optimazation of emulsion design for improved image quality.

FOOTNOTES FOR CHAPTER 1

[1] W. T. Hanson Jr. and C. A. Horton, "Subtractive Color Reproduction: Interimage Effects," Journal of the Optical Society of America, vol. 42, no. 9, September, 1952, p. 663.

THEORETICAL EXEGESIS

INTERIMAGE EFFECTS

Interimage effects are manifested to some degree in all color films, but the actual mechanism that produces them is difficult to specify. It has generally been shown through previous investigations that interimage effects are a direct result of the development process. Penetration of the developer into an emulsion and subsequent formation of an image involves numerous chemical and kinetic interactions. For instance, halide ions and other by products are released; diffusion rates vary from layer to layer; and, oxidation products are formed and react with couplers which must diffuse into the emulsion if not incorporated. These are just a few of the development related actions which contribute to the overall interimage effects. A published study cites the fact that depletion of the developing agent and accumulation of the bromide ions do not result in any significant interimage effects; however, iodide ions and their corresponding retardation effects are factors.[1] In addition, the presence of interlayers affects the overall interimage effects by inhibiting diffusion. In general, dye formation or development within an individual layer of a multiple

layer film is a function of the exposure received by all the photosensitive layers. The exact development mechanism or mechanisms resulting in interimage effects is not important to this study but rather the manifestation of these effects.

The actual existence of interimage effects is most readily apparent through analysis involving dye density comparisons. Development of a uniformily exposed tripack will yield an image with certain analytical densities. These densities will not be matched by development of the dye layers singularily. Previous investigations have clearly demonstrated this and have attributed the disparity to interimage effects. Probably one of the best studies on this was done by W. T. Hanson Jr. and C. A. Horton of the Kodak Research Laboratories. Their procedure was to compare equivalent neutral densities of a single color image with the corresponding color in a neutral image formed by equal exposures. Hanson and Horton showed that interimage effects in reversal films are recognizable and a fairly significant part of color reproduction.[2]

FILM CHARACTERISTICS AND STRUCTURE

The film chosen for this study of interimage effects was Kodak Ektachrome 160 Professional Film. It is a fast, professional, color, slide film balanced for exposure by a 3200K tungsten source and requiring storage at a temperature of 13C or below. The characteristic, spectral sensitivity,

and spectral dye density curves for this film are shown in Figure 2-1. Ektachrome 160 Professional Film was chosen for this study because of its characteristic curves and because it is typical of present day color reversal films and comparable to some color aerial film emulsions.

It is apparent with reference to the spectral sensitivity curves that there is a sensitivity overlap of the dye-forming layers. This is consistent with the functional purpose of the film to reproduce color corresponding to human observation. It would of course be better in this type of analysis of interimage effects to use a film in which the spectral sensitivities do not overlap or ideally use film base coated only with the desired photosensitive layer or layers. However, the first would be an atypical film and results would not be relevant to present day photographic systems. The second option is unavailable for this study and would, in addition, introduce other uncontrollable factors.

The structure of Ektachrome 160 Film is shown in Figure 2-2. The film has both a slow speed and high speed photosensitive layer for each of the three wavelength regions of the visible spectrum. The dye layers are seperated by interlayers which restrict the migration of the dyes. The interimage effects under study would be those occurring as a result of the level of development activity in layers 10 and 11, 6 and 7, and 3 and 4. Thus, the magenta image

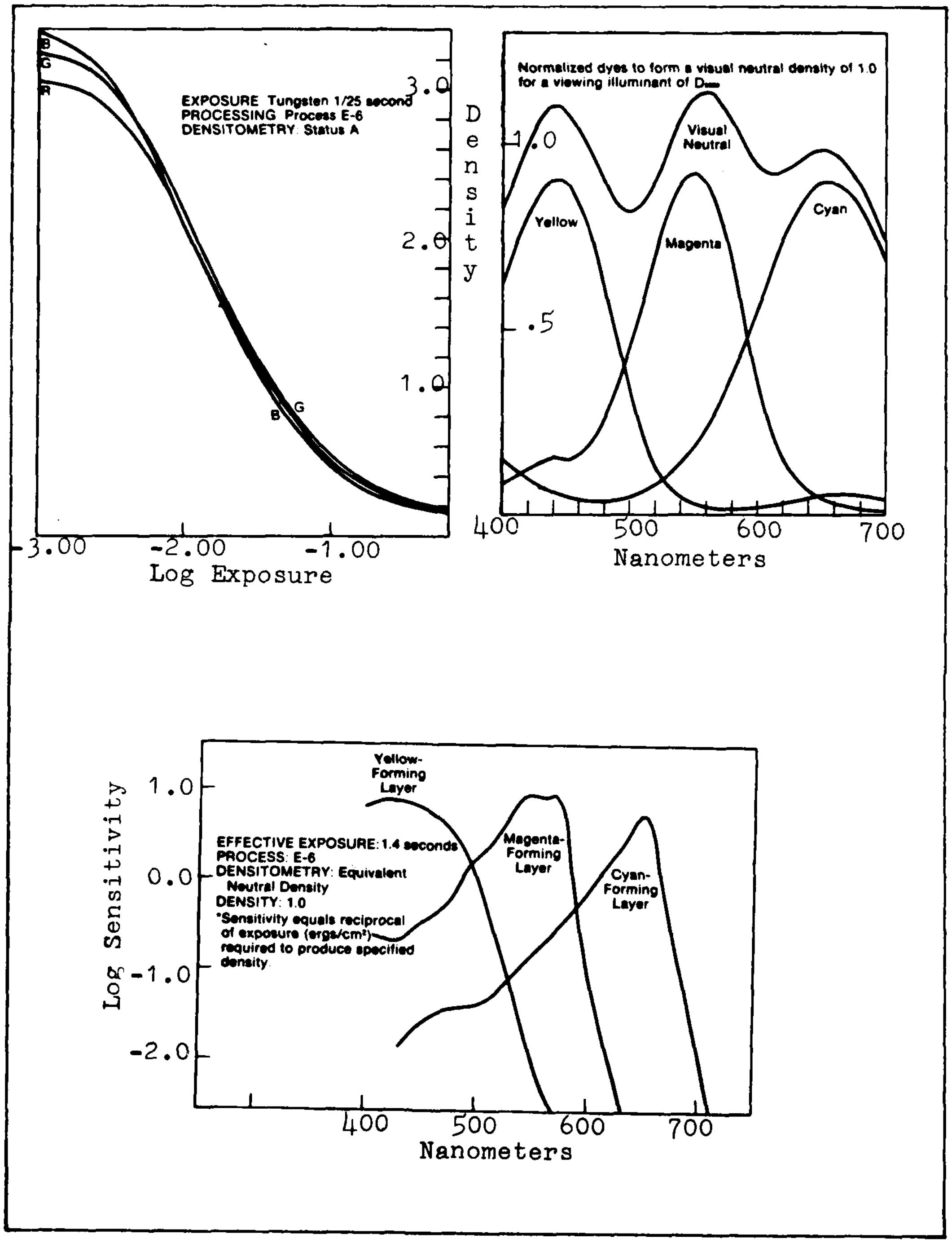

Fig. 2-1. Kodak Ektachrome 160 Film Data[3]

would be a function of the yellow and cyan images and vice versa. The MTF is dependent on the light scattering properties of the emulsion and usually the top layers will exhibit the highest MTF. This is because light distribution becomes more diffuse as it penetrates farther into the emulsion. It is also evident that any processing activities in the emulsion layers are diffusion dependent with the layer's distance from the top of the emulsion being a significant factor.

13	Single Overcoat
12	Gel Layer
11	Fast Emulsion (Blue-Sensitive)
10	Slow Emulsion (Blue-Sensitive)
09	Gel Layer
08	Gel Layer
07	Fast Emulsion (Green-Sensitive)
06	Slow Emulsion (Green-Sensitive)
05	Gel Layer
04	Fast Emulsion (Red-Sensitive)
03	Slow Emulsion (Red-Sensitive)
02	Gel Layer
01	Gel Layer
	Support

Fig. 2-2. Kodak Ektachrome 160 Film Structure[4]

The most common layer order for color films, both "negative" and "positive" has been blue-sensitive layer, yellow filter, green-sensitive layer and red-sensitive layer on top of a support. There have been and are some exceptions to this structure which have resulted in increases in resolving power. Notably, Kodak Aerial Color Film SO-242 and Kodak Aerochrome Infrared Film 2443. Incorporating dissimilar sensitivity responses for each layer and a top coated yellow filter, an increase in resolving power was achieved by changing the order of the light-sensitive layers. In the case of SO-242, it was changed to green, red, and blue. The increase in resolution was possible because the blue image-forming light is scattered to a greater extent by the atmosphere than the red and green. Therefore the blue-sensitive layer is placed at the bottom of the emulsion and the green-sensitive layer is moved up to the top where now fewer upper layers contribute to the diffusion of its image-forming exposure. This of course improves the Modulation Transfer of the green-sensitive layer and hence the visual MTF at the expense of the MTF of the blue-sensitive layer.

The structure of the film and the previous discussion of development actions leads to the conclusion that inter-image effects should indeed be present in the film under study. Analysis of these effects involves dye densities. Attention to the spectral dye density curves of the film, shown in Figure 2-1, illustrates the additive effect of the

three dyes when any color density readings are made. Since the film structure does not lend itself to individual layer analysis, procedures in colorimetry are necessary as a means of quantification.

COLOR SPECIFICATION

The specification of color is an important part of any study of reproduction capability of color films. The visual appearance of any dye image formed in a film by an exposure is dependent on the spectral power distribution of the source and the spectral sensitivity of the film in conjunction with the viewing illuminant and the spectral absorption of the dyes. Establishment of procedures to study interimage effects through the Modulation Transfer Function necessarily involves the analysis of dye images. Quantitative measurements and analysis procedures utilized in this study were developed and followed with regard to the CIE system of color measurement and the 1970 ANSI standard for viewing of transparancies.

The Commission Internationale de l'Eclairage (CIE) has standardized a system of colorimetric specification which is based on the 1931 Standard Observer and a set of color matching functions. The means of specification of a color can be either the CIE tristimulus values or the associated chromaticity coordinates--the designation, relationship, and calculation of which is shown in Appendix A. Samples having the same colorimetric specification will appear identical in

color when viewed by the standard observer and illuminated under specified conditions. The CIE system allows the comparison of transparencies which may or may not have identical spectral transmissions yet still be perceived as identical in color. Specification under the CIE system is dependent on the spectral distribution functions of an illuminant which can be any named source.

The American National Standard, ANSI PH2.31-1969, is a guide to the illumination of color transparencies for direct viewing. Although it deals primarily with the chromatic appearance of the illuminator surface and illuminant, the standard is relevant to this study since it can be assumed that samples are viewed under D_{5000} illumination. Major specifications in the standard are:

> 1. The chromaticity of the illuminator surface shall be approximately that of a CIE Daylight Illuminant at a correlated color temperature of 5000K....
>
> 2. The chromaticity coordinates of the illuminator surface shall lie on the locus of chromaticities corresponding to daylight illuminants...at a coordinate position of x = 0.3457, y = 0.3586, in the 1931 CIE Chromaticity Diagram defined by:
>
> | Points | Chromaticity Coordinates |
> |---|---|
> | 1 | x = 0.3297, y = 0.3373 |
> | 2 | x = 0.3273, y = 0.3497 |
> | 3 | x = 0.3596, y = 0.3770 |
> | 4 | x = 0.3572, y = 0.3612 |
>
> 3. The relative spectral power characteristics of the illuminator surface shall, ideally, be the same as those of CIE Illuminant D_{5000}.[5]

Specification of color is not always so rigorous and not always done with regard to the CIE Standard Observer and the viewing illumination. A given transparency illuminated by a source with a unique spectral energy distribution and observed according to a standardized procedure has a unique spectroradiometric transmission distribution. However, two transparencies can be visually identical in color and yet possess different spectroradiometric transmission distributions. In specific terms the colors are metameric. In accordance with the science of colorimetry, two colors are visually identical in color if they possess identical tristimulus values or chromaticity coordinates and have equal visual luminance. Colorimetry is not often used to specify images. In some instances, as with color film, the fact that the integral density curves "overlap" is considered as constituting a neutral color. Production control and testing of color films with respect to MTFs is done by producing sinusoidal images with an exposure giving "overlapping" integral density curves. This is considered a neutral image on which a visual MTF is determined using a visual filter which simulates the luminance response of the human eye.

The first condition to obtain good color reproduction is that neutrals in the original scene should look neutral in the reproduction. The procedure of realizing a visual neutral utilized in this study is based on the 1931 CIE Standard Observer and the 1970 ANSI standard for viewing of

slides. The images produced for this study will be spectrophotometrically evaluated and chromaticity coordinates computed with respect to D_{5000}. This will serve as a means for comparison of the neutral image with the three, seperate, color images. The spectrophotometric trace and subsequent calculations as outlined in the Appendix should yield chromaticity coordinates of $x = .3457$ and $y = .3586$ if the neutral sample is equal in color to D_{5000}. The neutral image and the color images will be evaluated according to colorimetry and PH2.31-1969. The chromaticity coordinates will serve as an indication of the degree of neutral for the tripack and as a means of comparison of the neutral and the color samples.

MODULATION TRANSFER FUNCTION

Previous discussion has centered on film characteristics, structure, and interimage effects relevant to a reversal film. Film samples produced for this study will be analyzed by edge gradient techniques in order to compute the Modulation Transfer Function. The theoretical basis for determining MTFs by edge analysis and the accuracy of this technique will be discussed only as it pertains to the experimental methods used in this study. Furthermore, the study will not attempt to prove or disprove the merits or usefullness of the MTF as a tool for image evaluation or as a quantifier of image quality. Numerous articles on the MTF and the method of edge analysis have previously been

published.[6-8] It was the intent of this study to show inter-image effects through the Modulation Transfer Function and also to investigate the MTF relationship between individual layers of the color tripack. A brief description of the Modulation Transfer Function is pertinent.

Consider a sinusoidal image consisting of a spectrum of spatial frequencies of various amplitudes and phases. The sinusoidal distribution of exposure is described by:

$$R(x) = R_0 + R_1 \cos(2\pi v x)$$

The values of the constants are:

R_0 = Average Exposure Value
R_1 = Exposure Amplitude
v = Spatial Frequency
x = Distance

If the modulation is defined by $M = R_1/R_0$, then the Modulation of the exposure within the emulsion and the modulation of the incident exposure can be expressed as a ratio called the Modulation Transfer Factor.

The Modulation Transfer Function is simply the relationship between the Modulation Transfer Factor and frequency. The relationship is expressed as a curve which graphically illustrates the output to input ratio of an emulsion or system over a certain frequency range. In lieu of imaging a sinusoidal object onto the film, mathematical procedures have been developed to compute MTFs from microdensitometer traces of edge images. This will be the procedure

used in this study.

Since the Modulation Transfer Function of an emulsion is computed from a developed image, it is logical that any image degradation will reduce the MTF. Image degradation is caused primarily by emulsion turbidity which causes an exposure distrubution due to scattering. This is especially significant for color emulsions which are thicker than black-and-white emulsions. The exposure distribution of an infinitely narrow line of light incident on the emulsion is referred to as the line spread function of the emulsion.

In addition to turbidity, other factors can affect the image to some degree. Some of the most significant are commonly known as adjacency effects. These are the discrepancies which arise between exposure and density distribution around a boundary seperating two areas of unequal exposure. In the case of an edge image, the border effect is manifested along the edge by an increased density within the high density area while the fringe effect is manifested as a decreased density within the low density area. These adjacency effects tend to enhance edge sharpness especially at low frequency. Adjacency effects are attributed to chemical actions of the developer and emulsion components and to a lesser degree, mechanisms of the processing procedure. This results in a unique Modulation Transfer curve in which the MTF may be higher than 100% at low frequencies.

Although adjacency effects can be removed from the MTF

by mathematical use of the chemical spread function, curves published by manufacturers include the effects of processing with the recommended chemicals. The Modulation Transfer Function for Ektachrome 160 Professional Film clearly illustrates the contribution of adjacency effects when processed in E-6 chemicals. Since this study is on interimage effects resulting from development, the chemical spread function will not be used. Comparisons between MTFs and between densities of the layers are possible with the adjacency effects included.

There has also been some speculation about the MTF of an emulsion being independent of exposure and development time. A study by Lamberts indicates that the times have little effect in the absence of any significant adjacency effects. Conversely, a study by Langner supposes that exposure level may have some influence.[9] Since the procedures in this study utilize standard processing concurrently on all samples and edge exposures were equal on the neutral and the seperations, the MTFs derived in this study will be considered as comparable in spite of any possible exposure effects.

The exposure distribution mentioned previously and referred to as the spread function of the emulsion is the basis for MTF derivation by edge gradient analysis. In the case of an edge image, the microdensitometer trace is a summation of overlapping individual line spread functions at various points across the edge. This is illustrated in Figure 2-3.

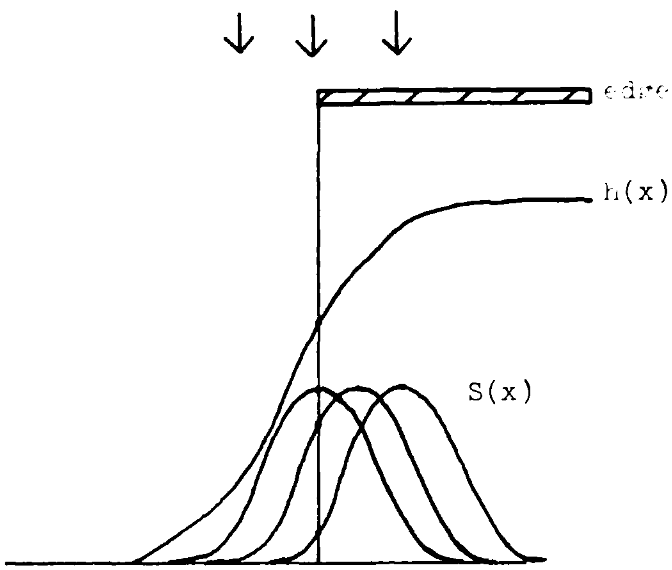

Figure 2-3. The Edge Spread Function

If h(x) is the effective exposure edge as illustrated in Figure 2-3, then:

$$\frac{dh(x)}{dx} = S(x)$$ where S(x) is the line spread function.

The spread function can then be Fourier transformed and normalized to yield the MTF.

$$\left| \frac{\int_{-\infty}^{\infty} S(x) e^{-i2\pi vx}}{\int_{-\infty}^{\infty} S(x) dx} \right|$$

The steps of the procedure combining the step wedge exposure and the edge trace leading to the MTF are shown in Appendix B. This method is covered in an article written by R. A. Jones and "...has been found to produce reliable results for a wide variety of cases."[8]

FOOTNOTES FOR CHAPTER 2

[1]H. D. Meissnee, "On the Mechanism of Interimage Effects," Photographic Science and Engineering, vol. 13, no. 3, May-June, 1969, p. 141.

[2]W. T. Hanson Jr. and C. A. Horton, "Subtractive Color Reproduction: Interimage Effects," Journal of the Optical Society of America, vol. 42, no. 9, September, 1952, p. 663.

[3]Eastman Kodak Company, Sensitometric and Image Structure Data for Kodak Color Films, E-78-26, Rochester, 1977.

[4]Eastman Kodak Company, Finished Film Cross-Section Sheet, Rochester, March, 1978.

[5]American National Standards Institute, Inc., American National Standard-Direct Viewing of Photographic Color Transparancies, New York, 1969.

[6]Frank Scott, Roderic M. Scott, and Roland V. Shack, "The Use of Edge Gradients in Determining Modulation-Transfer Functions," Photographic Science and Engineering, vol. 7, no. 6, November-December, 1963, p. 345.

[7]M. DeBelder, J. Jespers, and R. Vergrugghe, "On the Evaluation of the Modulation Transfer Function of Photographic Materials," Photographic Science and Engineering, vol. 9, no. 5, September-October, 1965, p. 314.

[8]Robert A. Jones, "An Automated Technique for Deriving MTF's from Edge Traces," Photographic Science and Engineering, vol. 11, no. 2, March-April, 1967, p. 102.

[9]W. N. Charman and A. Olin, "Image Quality Criteria for Aerial Camera Systems," Photographic Science and Engineering, vol. 9, no. 6, November-December, 1965, p. 385.

HYPOTHESIS

The discussion of the previous chapter has centered on basic theory and previous findings related to the direction of this study as outlined in the introduction. With reference to the second chapter, it is useful to restate the hypothesis of this study in more specific terms.

Considering the studies already done on interimage effects, development effects, and film structure, it is a valid conclusion that there are some interimage effects present in processed Ektachrome 160 Professional Film. The hypothesis of this study is that these effects in reversal films do in some way manifest themselves through the effective Modulation Transfer Function. Although the exposure techniques used in this study will not allow proving the existence of interimage effects through dye densities, they will, however, tend to maximize these effects through the increased development in the seperations.

The acceptance of the existence of interimage effects allows the effective Modulation Transfer Function to become the main interest of this study. Since the Modulation Transfer Function for an emulsion is constant and since small density differences do not affect the MTF, then two MTFs of

the same color, one from a seperation and one from a tripack, should possess equal MTFs in the absence of any interlayer effects. Also, if the tripack is a visual neutral confirmed through colorimetry, then its visual MTF curve can be compared to manufacturer's published data.

Consisely, it is the hypothesis of this study that interimage effects are manifested through the effective MTF of a reversal material and to a greater degree in any seperations which will be indicated by modified MTF curves. The method of MTF analysis used in this study, combining colorimetry and edge analysis can be proposed as a possible method of measuring MTFs of color transparencies for incorporation as an industry standard. Furthermore, the overall analysis of MTFs of seperations and tripacks can reveal differences which can lead to anomalous emulsion design, incorporating interimage effects and film structure, for image quality optimization.

EXPERIMENTAL PROCEDURES

The characteristics and structure of a color film limit the sensitivity or densitometric response which can be accurately attributed entirely to one layer. Sensitometric evaluation of a color film involves the determination of three characteristic curves which result from the integrated effect of all layers. In a reversal film, it is necessary that the three curves coincide to produce a neutral color. Fortunately, these curves need not overlap precisely to be judged neutral by the human eye. Densitometry of reversal films is complicated because the three dyes used have overlapping absorption curves. MTF analysis must be approached with the above considerations in mind. In order to complete this study of interimage effects and the MTF of individual layers, film samples were produced which allowed the analysis of single color dye images. The desired procedure was to reduce the developed dye density levels of two dyes to a minimum by overexposure and imaging onto the third dye producing layers maintained at a lower pre-exposed level. The single color images can then be compared to three color images in which the dye densities are approximately equal.

PRODUCTION OF SAMPLES

A. Apparatus

The production of the exposed film samples used in this study utilized a 25 watt tungsten halogen source, Kodak Ektachrome 160 Professional Film, Kodak Wratten Filters, and a 35mm camera body. A diagram of the physical apparatus is shown in Appendix C. An external shutter was mounted on the light source and controlled by an electric timer. A transformer was included in the electrical circuit to produce the 12 volts required for the light source; and, a voltage regulator was used to minimize any changes in the color temperature of the light source.

The film was exposed in the camera body which was used without a lens and shutter. The use of the camera body allowed repeat registration of subsequent exposures onto a 35mm frame following rewinding of the film. Rewinding was necessary because the step tablet or the edge had to be inserted into the camera between the film and over the film plane opening after flashing on the entire roll had been done. Pressure from the camera platen on the film base was effective in obtaining good contact between the edge, step tablet, and emulsion. Because of this pressure, the camera back was opened in darkness when advancing the film to the next frame whenever the edge or step tablet was inside the camera. This was done to eliminate any chance of scratching

the emulsion.

A neutral density step tablet was modified to fit the size of a 35mm frame. This was done by cutting the step tablet into three strips of seven steps each giving 21 density steps. The strips were mounted by the edges on a microscope glass. The microscope glass was put in a frame made of estar to fit the film plane of the camera and also be held firmly in position over the camera shutter opening. The same framing technique was used for the edge which was approximately the same dimensions.

B. Filtered Exposures

The filter combinations and exposure times used in the production of the film samples were determined after numerous trials and are listed in Table 1. Film rolls of 100 feet in length were used in order to maintain emulsion characteristics from trial to trial within each roll of film. The samples were produced by flashing the film through selective filters so that when developed two of the integral dye densities would be at a level of .5 with the third at 1.5. A subsequent colored imaging exposure of the contacted step tablet or edge was given to the least exposed layers. The neutral color patches were produced by first flashing the film to the 1.5 density level with a neutral exposure and then superimposing the three imaging exposures used for the single color patches. These procedures produced a series of

Table 1. Filters and Exposure Times

Sample	Filter	Flash Time	Filter	Flash Time	Imaging Filter	Imaging Time
Yellow	23A	1+3/4	.9ND	$\frac{1}{60}+\frac{1}{125}$	94	1+1/8
Magenta	36	$\frac{3}{8}+\frac{1}{15}$	92	$\frac{1}{60}$	93	1.0
Cyan	44A	$\frac{1}{8}+\frac{1}{30}$	93	1.0	92	$\frac{1}{60}$
Neutral	.9ND CC05B CC20C	$\frac{1}{30}+\frac{1}{60}$			94 93 92	1+1/8 1.0 $\frac{1}{60}$

yellow, magenta, cyan and neutral color images of density steps and the edge.

Production of the yellow image was accomplished by flashing the green and red-sensitive layers using a Kodak Wratten Filter No. 23A. Figure 4-1 shows the absorption curve of the filter overlapping the spectral sensitivity curves of the film. This filter gave excellent seperation of the blue-sensitive layers. Since the blue-sensitive layers remained relatively unexposed, it was necessary to give the film a neutral exposure to reduce yellow dye formation to the target 1.5 integral density level. The blue, image-forming exposure was then given to the film through a Kodak Wratten Filter No. 94 whose absorption curve is shown in Figure 4-2.

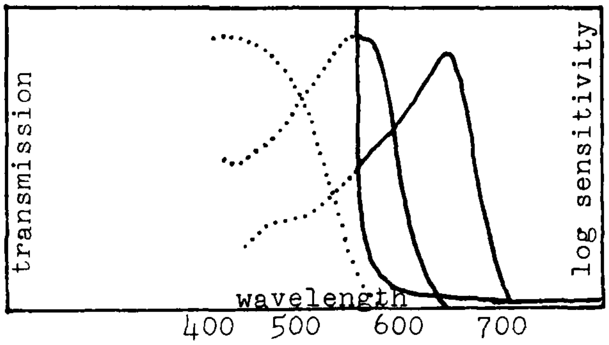

Fig. 4-1. Filter No. 23A Transmission

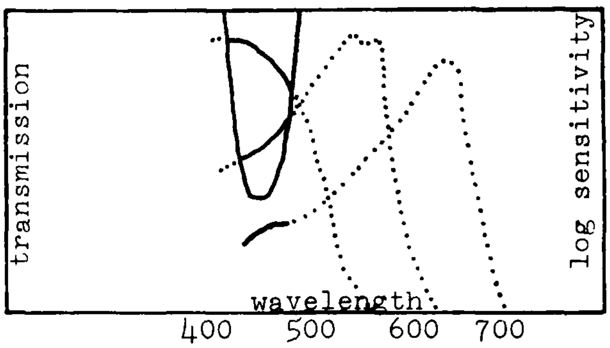

Fig. 4-2. Filter No. 94 Transmission

The magenta image was formed by first flashing the blue and red-sensitive layers using a Kodak Wratten Filter No. 36 and then a Kodak Wratten Filter No. 92 to further expose the red-sensitive layers. Figure 4-3 shows the applicable filter absorption curves as they relate to the spectral sensitivity curves of the film. This combination resulted in a minimization of dye formation in the blue and red-sensitive layers while achieving the target exposure level for the green-sensitive layers. The magenta image was then formed by

exposing the film through a Kodak Wratten Filter No. 93 whose absorption curve is shown in Figure 4-4.

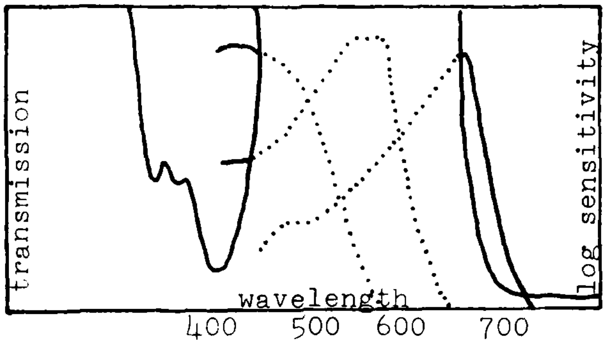

Fig. 4-3. Filter No. 36 Transmission

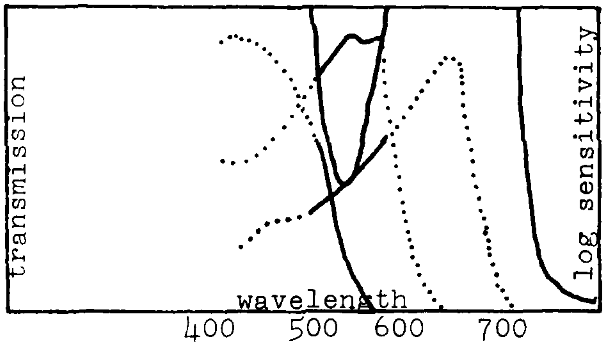

Fig. 4-4. Filter No. 93 Transmission

Production of the cyan image was accomplished by first flashing the film through a Kodak Wratten Filter No. 44A and then a Kodak Wratten Filter No. 93. Again, this minimized and balanced the developed integral dye densities in the blue and green-sensitive layers. Figure 4-5 shows the relationship between filter absorption and film sensitivities for these exposures. The cyan image was then exposed onto the film through a Kodak Wratten Filter No. 92 whose curve

is shown in Figure 4-6.

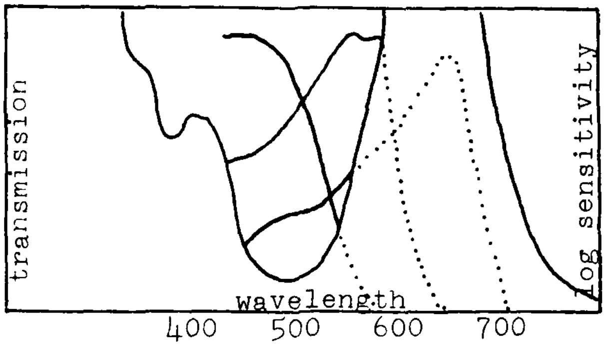

Fig. 4-5. Filter No. 44A Transmission

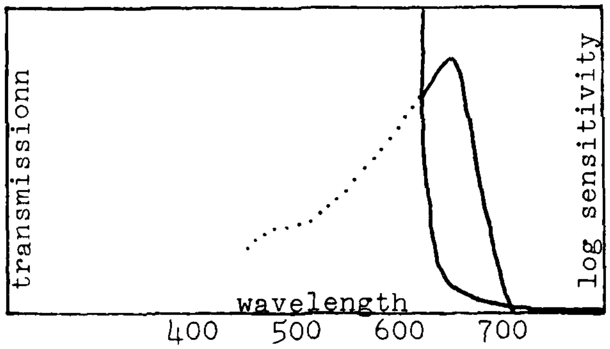

Fig. 4-6. Filter No. 92 Transmission

The neutral color image was produced by flashing the film through a filter pack which yielded the approximate target exposure levels simultaneously in all image-forming layers. The image-forming exposures used on the yellow, magenta, and cyan dye-forming layers were then repeated onto the film. The composite of these exposures yielded the neutral color step tablet and edge images.

C. Processing

As previously stated in Chapters 1 and 2, processing with its associated development effects is a factor with which any study of the Modulation Transfer Function must consider. In this study, procedures were used to minimize any effects caused by improper or unrepeatable processing. Processing during initial trials to determine exposure times and filtration was done manually with a reel and tank using E-6 chemicals. After determining the approximate times and filtration which gave the desired results, processing was done on an E-6 machine processor. All exposures were made on the same roll of film and received the same processing. The machine processor which was used is controlled to maintain control strip color within the limits of a .05CC filter. Thus, minor corrections on subsequent film rolls, of exposure times or filter packs, could be made as necessary to approach the desired densities. Storage time for the samples used in this study after exposure and prior to processing was 18 hours and below 13C in temperature.

ANALYSIS OF SAMPLES

A. Densitometry

Density measurements of the processed film samples were made with a calibrated MacBeth densitometer utilizing Kodak Densitometer Filter Set AA (Certified). All density values and characteristic curves in this study were determined using Status A densitometry which is recommended for color positive materials. The END densities were indirectly obtained from the integral densities through computation. This was accomplished through the use of conversion equations which the Eastman Kodak Company maintains on Ektachrome 160 Professional Film.

B. Spectrophotometry

Data for colorimetric calculations was generated by analyzing the high density half of the edge image samples with a spectrophotometer. The spectral transmission of each sample was evaluated at one nanometer wavelength intervals between 400 and 700 nanometers. The neutral image was evaluated singularily while the cyan, magenta, and yellow images were evaluated singularily and also as a composite. This of course resulted in higher densities for the composite. Spectrophotometer output was in the form of diffuse transmission density recorded in digital format out to seven decimal places. Calculations to determine chromaticity coordinates were done at ten nanometer intervals using the 1931 CIE Color

Matching Functions weighted by the relative spectral energy distribution of daylight at 5000K.

C. Microdensitometry

The American National Standards Institute has not published an ANSI standard for MTF evaluation of color materials. The ANSI standard for black-and-white films, ANSI PH2.39-1977, outlines a method for measuring MTFs and for production and evaluation of sinusoidal images. The section of the standard dealing with evaluation utilizing microdensitometry was considered in the procedures used in this study. However, since there is no standard for color materials, the microdensitometry was performed with optics giving what appeared to be the best results or least amount of noise due to granularity.

The microdensitometer used in this study was equipped with incorporated filters, an optical viewing system, electronic position control, and a digital computer. Alignment and focus of the samples was done visually by reference to the magnified dye structure of the emulsion. The computerized position control allowed the scanning optics to be returned to the same x and y coordinate position on the film sample. Microdensitometer density readings were processed by computer and printed in digital form. Statistical analysis of the stepped exposures was performed and led to the final use of a scanning slit measuring 12 micrometers by

400 micrometers. This slit size reduced the noise level to an acceptable degree and was narrow enough not to obscure the transfer function of the film.

Microdensitometer readings were taken through Status A filters on the step tablet image, the edge image, the step tablet object, and the edge object. The stepped images were scanned twice with 100 density readings taken on each step and statistical analysis was done by computer. The edges were traced across a total distance of 400 micrometers with a density reading generated at each one micrometer interval. Neutral film samples were scanned sequentially through the red, green, blue, and visual filters. The single color samples were traced with the complementary color filter only. Traces were made across the identical areas on each edge by cross hair alignment and reference to a common image point.

CALCULATION OF MTF

A. Edge Analysis

Microdensitometer readings were manually processed to generate the necessary data for computer analysis. This was done because of limited availability of computer time and also because the MTF program could not accept raw data generated by the microdensitometer. Manual processing of data is undesirable because of problems with precision and accuracy in conversions and smoothing; however, a conscientious effort was made to minimize errors.

Data processing consisted of graphical plotting, hand smoothing of curves, and visual determination of values on the curves. Densities from the scans of the stepped images and the stepped object were cross plotted and the resulting exposure curve was hand smoothed. The neutral sample yielded four exposure curves--one each from the visual, red, green, and blue scans. A single exposure curve was plotted for each seperation. Density values for the edge scans were also plotted and smoothed manually in the same fashion. This was difficult in that noise was prevalent on the high density side of the edges and a well defined trend in the curve above the shoulder was masked.

Exposure edge data for use in the MTF computer program were obtained by combination of the exposure curve and edge densities as shown in Appendix B. Relative exposure values were obtained by changing to transmission the density on the step object corresponding to an image density at a certain displacement across the edge. The relative exposure versus distance curve was completed by sampling at one micrometer intervals across the target edges and at four micrometer intervals on the image edges. This was relatively arbitrary with respect to time limits for computer input but allows the necessary frequency range of the MTF to be covered in accordance with the relationship:

$x = 1/2k$ where k is the spatial frequency in cycles/mm.

In the case of Ektachrome 160, the value of $k = 125$ cycles/mm

is sufficient. The sampling interval of one micrometer allows the MTF of the microdensitometer scan of the edge target to be presented out to 500 cycles/mm. The edge curves for the object and the image edge samples are shown in Appendix E along with the MTFs of the microdensitometer.

B. MTF Computer Program

The computer program utilizing edge gradient analysis to compute the Modulation Transfer Function is presented in Appendix D. Exposure edge data was utilized basically as presented in Appendix B with one addition. A Hanning window or raised cosine curve was used as a sampling window on the spread function. Multiplying by the window cuts off the unsymetric spread function and smoothly extends the values to zero. The resulting function was Fourier transformed and normalized to yield the MTFs. Computer output of edges and the MTF curves was in graphic form on a CRT viewer and copies were made by an optical printer. The MTFs for the film were computed by simply dividing the MTF of the edge images by the corresponding MTF of the edge target.

EXPERIMENTAL RESULTS

The results of this study under the previously outlined procedures basically fall into three categories: density, chromaticity, and MTF values. These values will be presented and evaluated independently as well as in combination with the intent of showing any interimage effects present.

The exposure procedures outlined in Chapter 4 achieved the desired density values and are presented in Table 2. Equivalent Neutral Densities are presented as an item of information only. The integral densities listed are averages of the steps on four seperate samples for each color. The maximum standard deviation between samples was .02 density. The characteristic curves of the samples are shown in Figures 5-1 thru 5-4. Values and curves for the neutral sample indicate good density balance and neutral color along the straight line portion and correspond well with the upper portion of the published curves for Ektachrome 160 Film. The maximum density value for the yellow image was about .10 lower than desired but this is not considered to have any significant effect on the MTF results. The blue and the green curves of the yellow and magenta images compare very favorably with the blue and green curves of the neutral.

Table 2. Densities of Samples

YELLOW SAMPLE

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.13	.21	.58	.14	.20	.63
.13	.22	.67	.14	.20	.74
.13	.23	.78	.14	.19	.86
.13	.23	.87	.14	.18	.96
.13	.24	.99	.14	.18	1.09
.13	.25	1.08	.14	.18	1.19
.13	.26	1.13	.14	.19	1.25
.13	.27	1.21	.14	.19	1.34
.13	.28	1.26	.14	.19	1.39
.13	.29	1.30	.14	.20	1.44
.13	.29	1.33	.14	.20	1.47
.13	.29	1.36	.14	.19	1.50
.13	.29	1.37	.14	.19	1.51
.13	.30	1.38	.14	.20	1.52
.13	.30	1.38	.14	.20	1.52

MAGENTA SAMPLE

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.41	.56	.31	.40	.64	.25
.42	.71	.33	.38	.84	.24
.43	.84	.35	.37	1.00	.24
.44	.95	.38	.36	1.14	.25
.45	1.06	.40	.35	1.28	.25
.46	1.17	.43	.34	1.42	.26
.47	1.25	.44	.34	1.52	.26
.48	1.35	.47	.33	1.65	.28
.50	1.42	.49	.34	1.74	.28
.50	1.46	.50	.33	1.79	.29
.50	1.49	.50	.32	1.83	.28
.51	1.51	.51	.33	1.85	.29
.51	1.53	.52	.33	1.88	.30
.51	1.53	.52	.33	1.88	.30
.53	1.53	.52	.33	1.88	.30

Table 2. (cont)

CYAN SAMPLE

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.53	.30	.31	.60	.28	.29
.68	.31	.31	.77	.27	.28
.88	.34	.32	1.01	.27	.28
1.04	.36	.33	1.20	.26	.27
1.18	.39	.34	1.36	.28	.27
1.30	.41	.35	1.51	.28	.28
1.38	.43	.36	1.60	.29	.28
1.43	.44	.36	1.66	.29	.27
1.48	.45	.36	1.72	.30	.27
1.51	.46	.37	1.75	.31	.28
1.53	.46	.37	1.78	.30	.28
1.54	.47	.37	1.79	.31	.28
1.55	.47	.37	1.80	.31	.27
1.55	.47	.37	1.80	.31	.27
1.55	.47	.37	1.80	.31	.27

NEUTRAL SAMPLE

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.50	.54	.57	.52	.56	.54
.63	.68	.68	.65	.71	.63
.82	.84	.81	.84	.87	.74
.95	.95	.91	.98	.98	.83
1.08	1.05	1.03	1.12	1.07	.94
1.18	1.15	1.14	1.22	1.17	1.04
1.24	1.22	1.22	1.28	1.24	1.12
1.31	1.31	1.33	1.35	1.33	1.22
1.35	1.36	1.41	1.39	1.38	1.30
1.38	1.42	1.44	1.41	1.45	1.32
1.39	1.43	1.47	1.43	1.45	1.35
1.40	1.44	1.49	1.44	1.46	1.37
1.41	1.45	1.49	1.45	1.48	1.37
1.41	1.45	1.50	1.45	1.47	1.38
1.41	1.45	1.51	1.45	1.47	1.39

Table 2. (cont)

Yellow Edge Sample

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.13	.21	.66	.14	.18	.73
.13	.28	1.38	.14	.18	1.53

Magenta Edge Sample

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.41	.67	.33	.38	.78	.25
.50	1.53	.52	.32	1.88	.30

Cyan Edge Sample

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.65	.30	.31	.74	.26	.28
1.54	.45	.35	1.79	.29	.26

Neutral Edge Sample

Red	Integral Green	Blue	Cyan	E.N.D. Magenta	Yellow
.61	.64	.68	.63	.66	.64
1.41	1.46	1.53	1.44	1.48	1.41

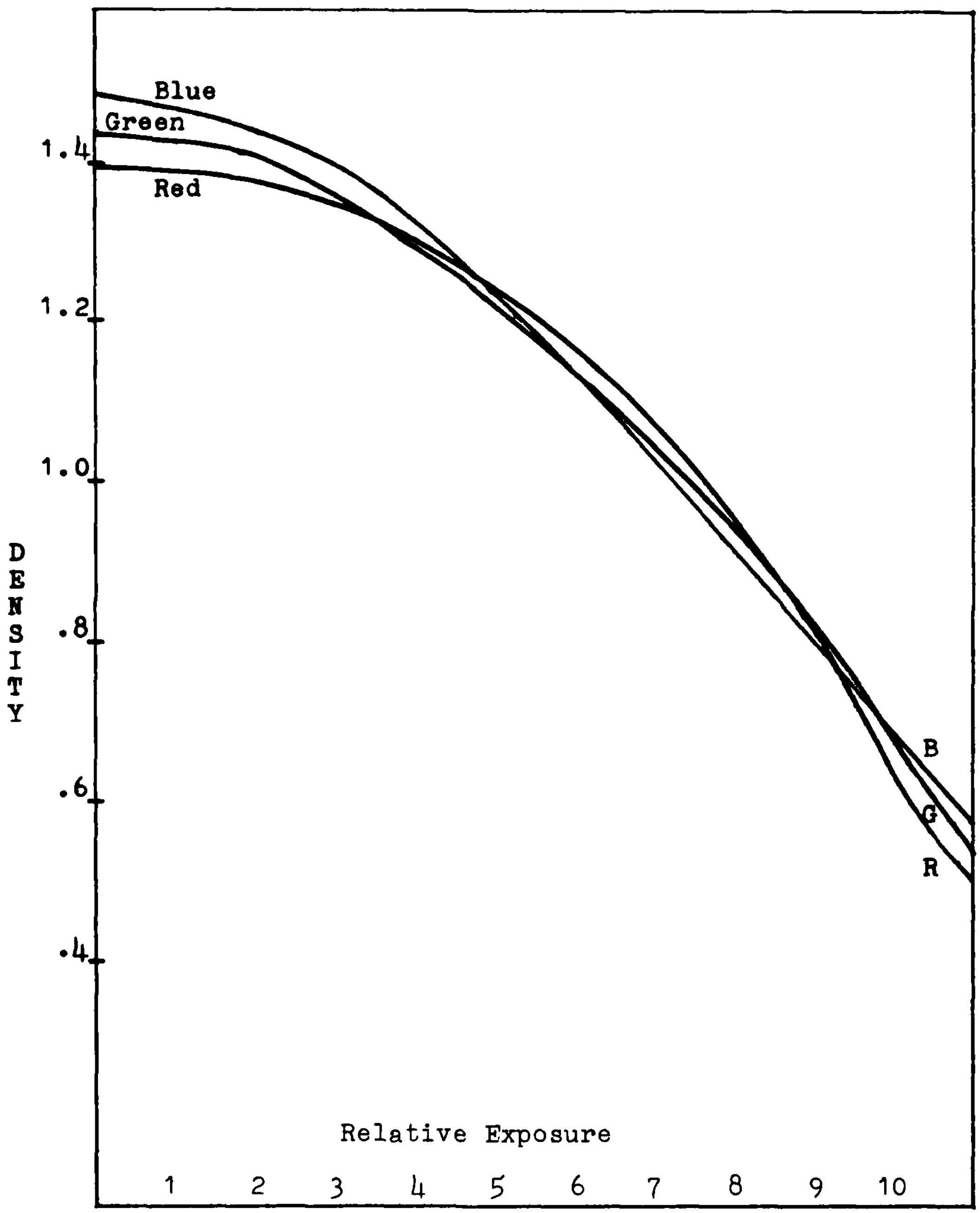

Fig. 5-1. Neutral Characteristic Curves

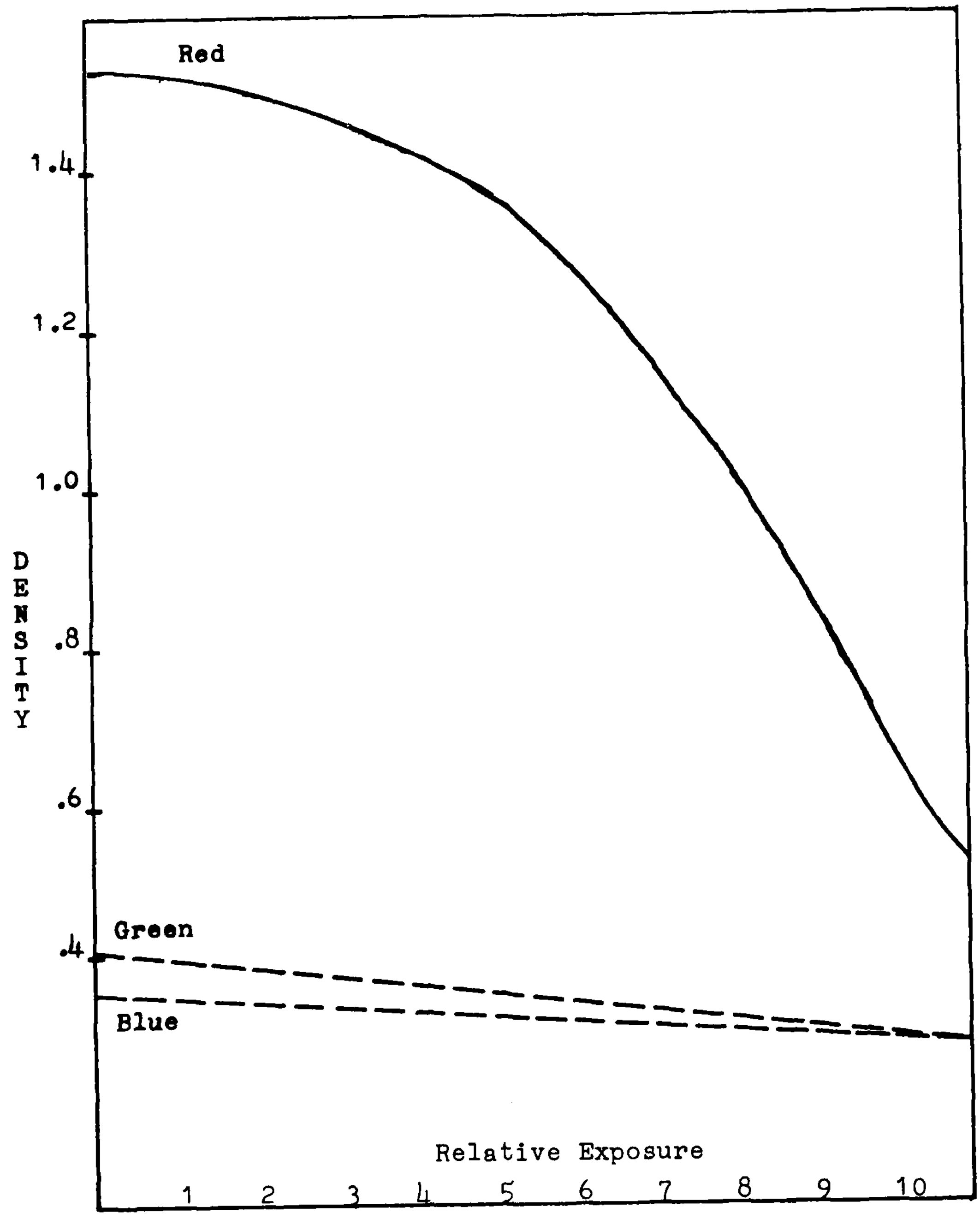

Fig. 5-2. Cyan Characteristic Curves

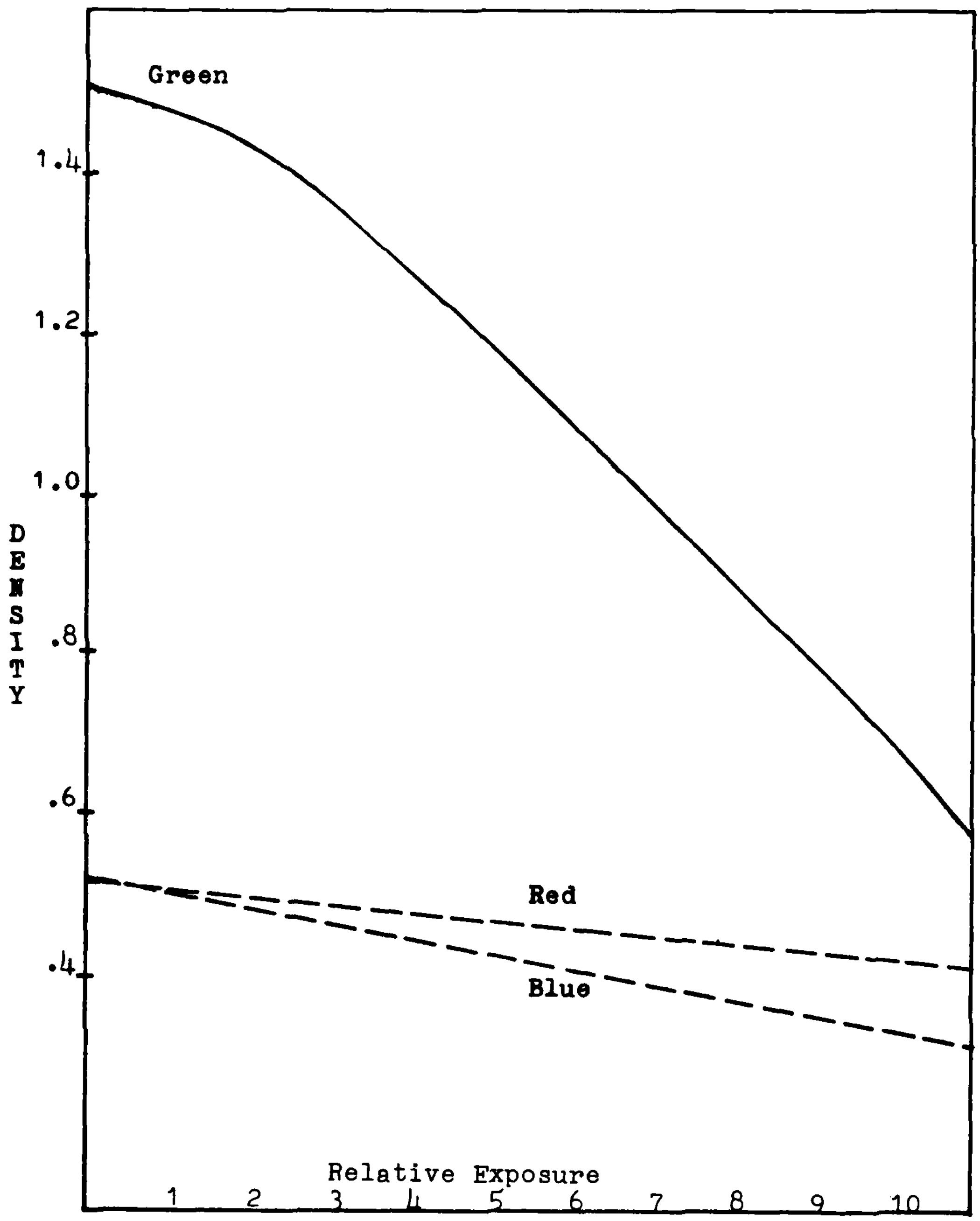

Fig. 5-3. Magenta Characteristic Curves

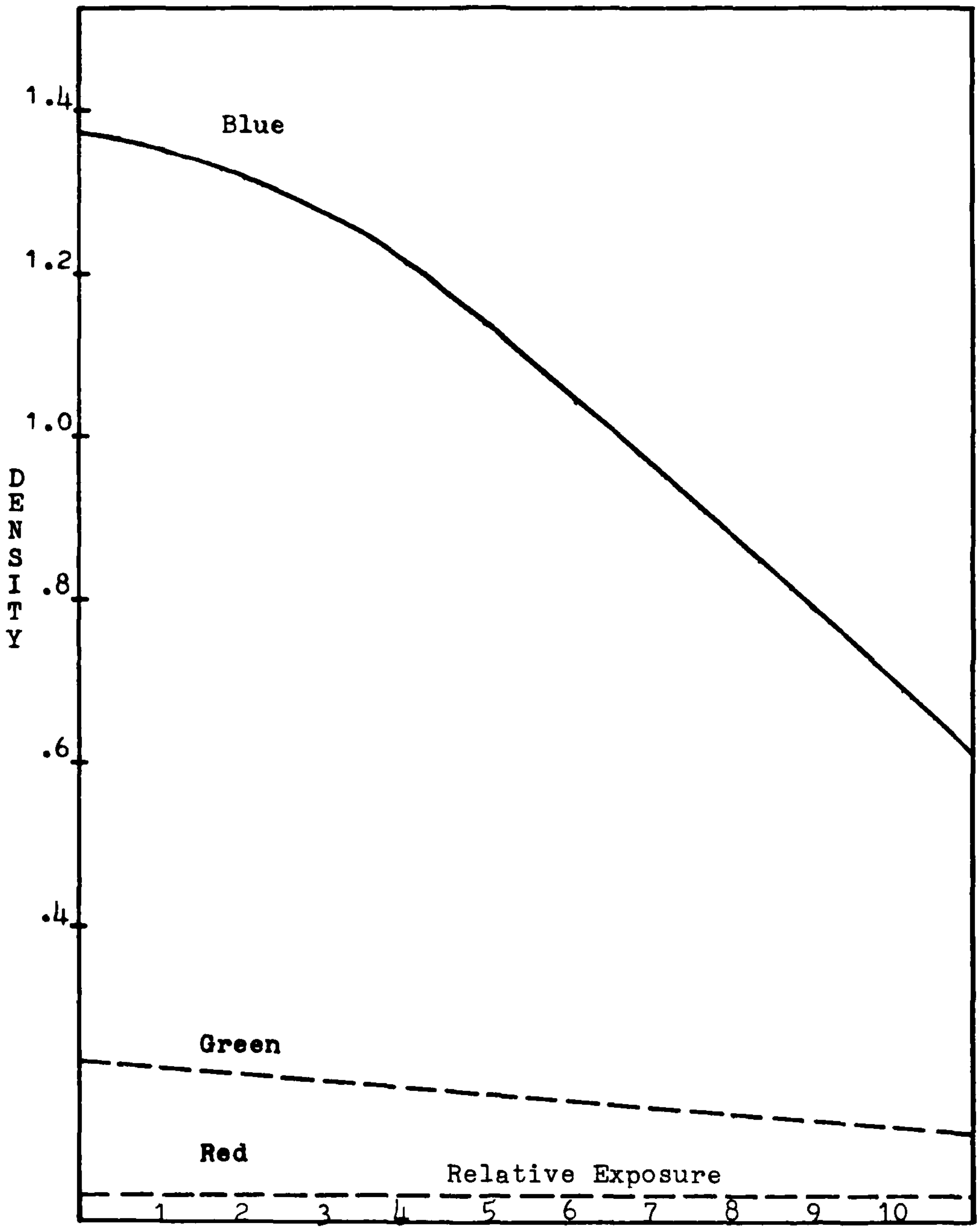

Fig. 5-4. Yellow Characteristic Curves

Chromaticity coordinates were computed for the neutral sample, the seperations and the composite. Chromaticity coordinates for the neutral were determined to be x = .3407, y = .3688 and plot just outside the tolerances listed in ANSI PH2.31-1969. Because of calculation procedures, this is close enough to consider the sample as a neutral color for MTF analysis. The points of the samples are indicated on the color diagram in Figure 5-5. The composite of the three seperations was determined from the sum of the seperation densities at each wavelength. The composite chromaticity cannot be strictly compared to the neutral's since two extra layers of support material and residual dyes are involved. The individual spectrophotometric density traces of the seperations shown in Figure 5-6 thru 5-9 correspond very nearly in shape to the published spectral dye density curves of the film. This is an indication that very little dye remains in the adjacent layers of the seperations. Since the spectral dye density curves correspond closely to the published curves as shown in Figure 2-1, the three seperations as a tripack should produce a good visual neutral suitable for comparison with the neutral sample.

The integral density values and spectrophotometric traces indicate that minimization of dyes in the desired layers of the seperations has been achieved and that density levels are relatively equal between the seperations and the neutral. The visual neutral color of the neutral sample

indicated by density values and chromaticity coordinates allows its use as a standard for comparison with the seperation MTFs. The integral density steps for the edge samples shown in Table 2 show good agreement between samples. Steps in the seperations being .72, .86, and .89 compared to .80, .82, and .85 for the neutral. The ENDs indicate a somewhat higher step in the magenta and cyan samples which is an indication that the magenta and cyan layers contain a greater amount of dye than the yellow or the neutral. This is probably the result of the overlapping exposures in the neutral.

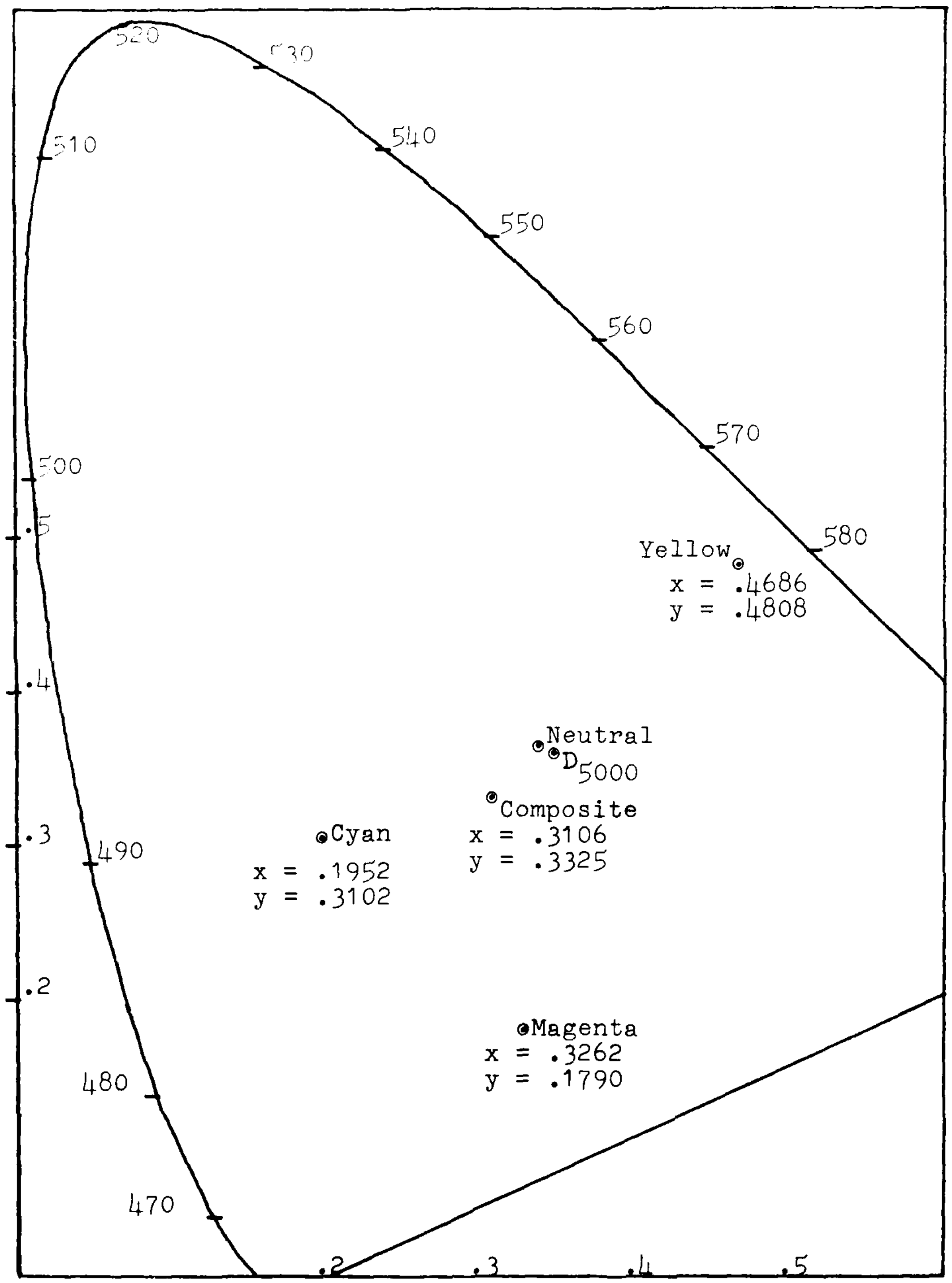

Fig. 5-5. Chromaticity Diagram

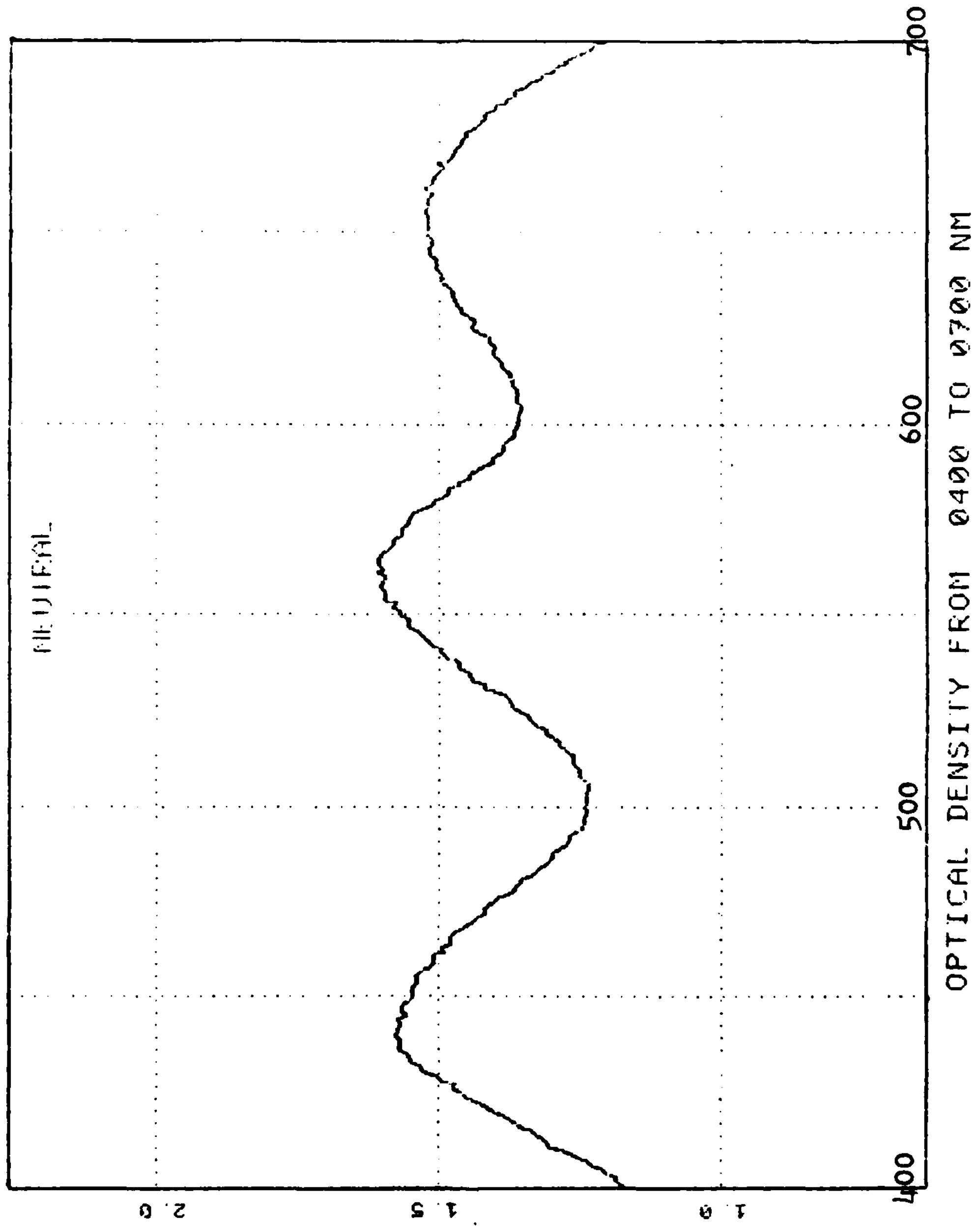

Fig. 5-6. Neutral - Spectral Density

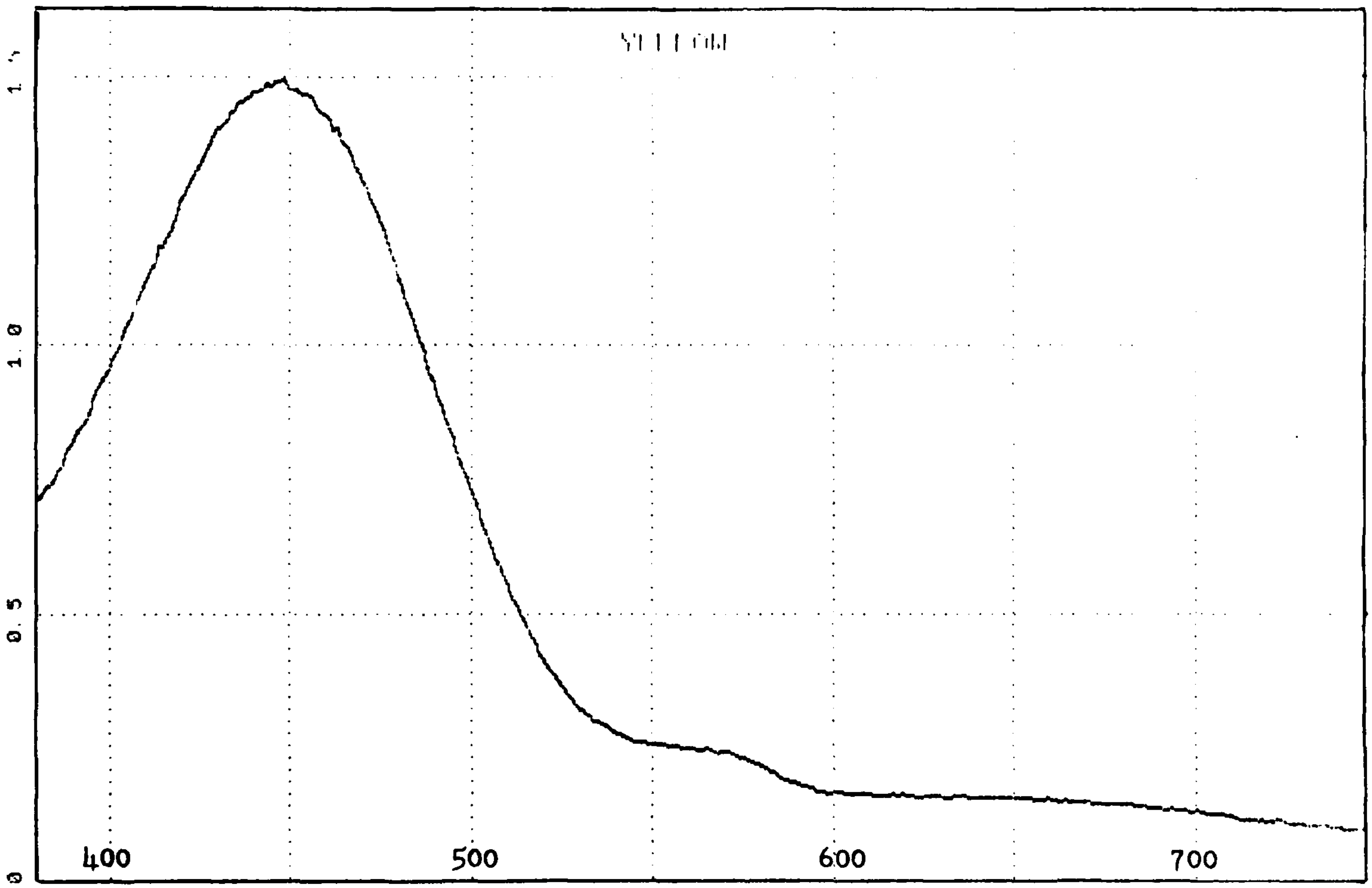

Fig. 5-7. Yellow - Spectral Density

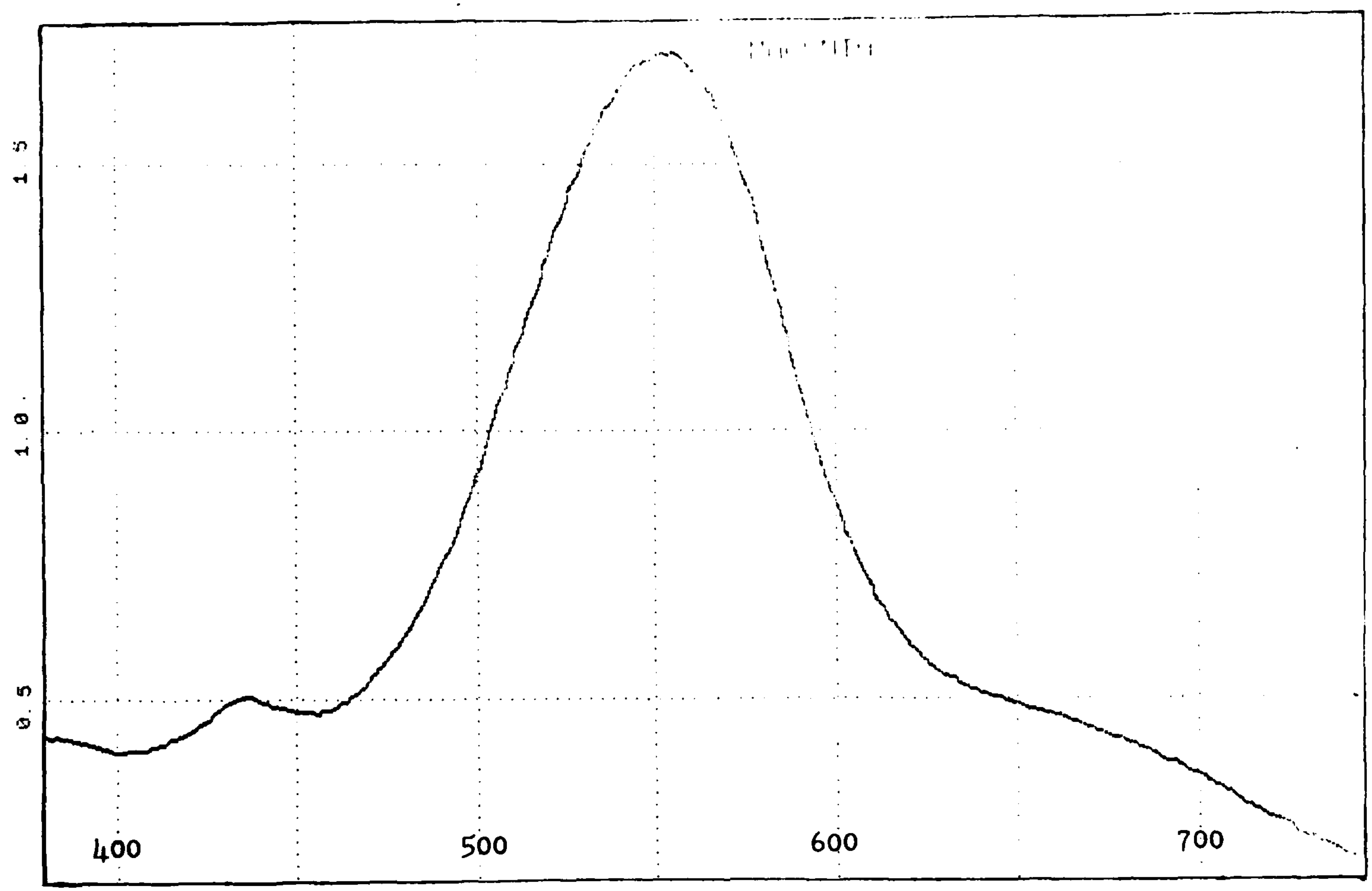

Fig. 5-8. Magenta - Spectral Density

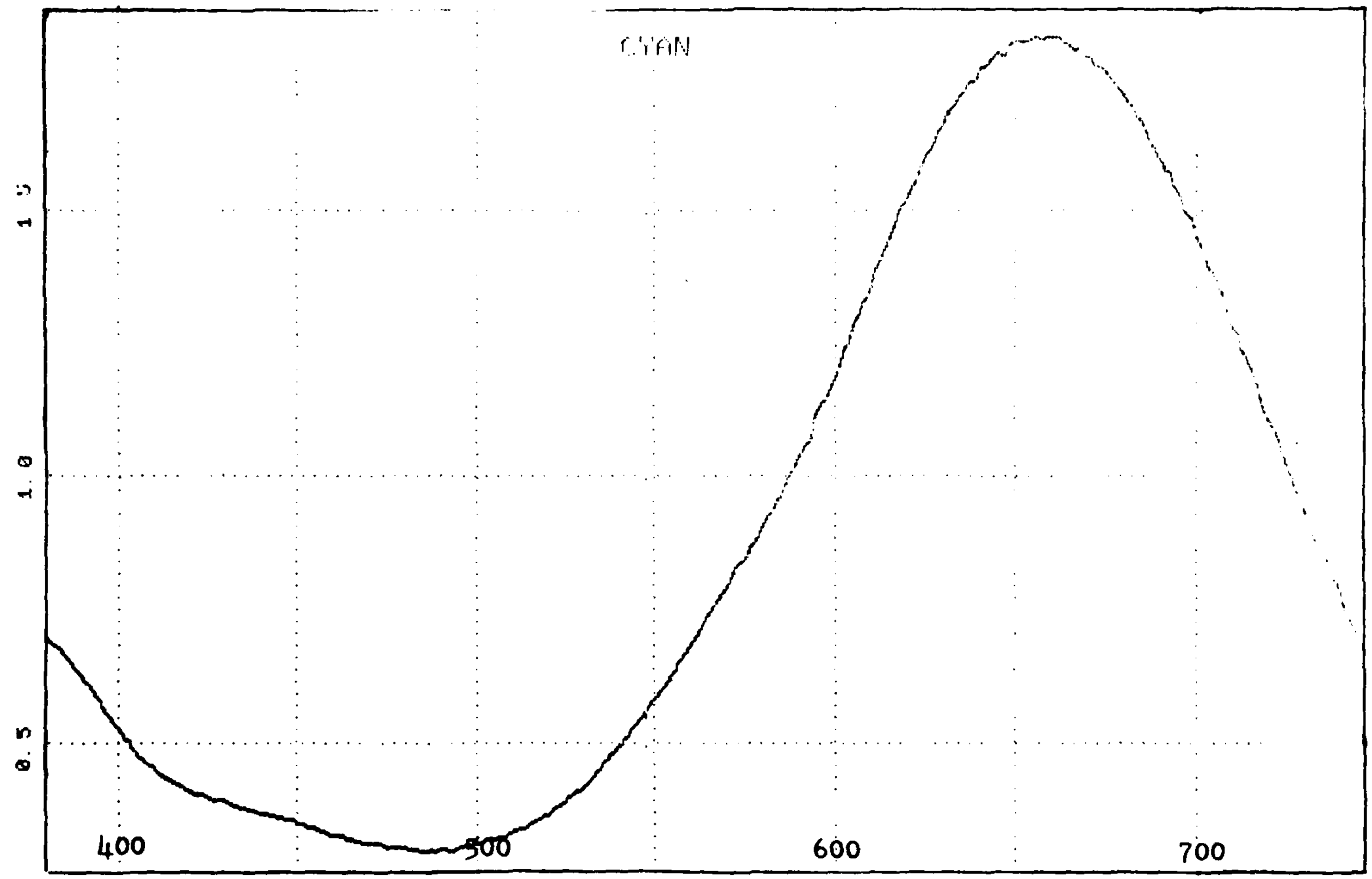

Fig. 5-9. Cyan - Spectral Density

The results of this study in the form of MTF curves are shown in Figure 5-10 thru 5-12. These curves are drawn on a full log scale as most color MTFs are published. The linear curves are shown in Appendix E. Figure 5-10 is a comparison of the experimental visual MTF determined in this study and the published MTF curve for Kodak Ektachrome 160 Professional Film. The experimental MTF does not exhibit any adjacency effects nor is it as high as the published MTF. This is probably due to several things. Mainly, the exposures were almost entirely on the linear portion of the characteristic curve, machine processing was used, and the film-microdensitometer combination was assumed to be linear. The small disparity at higher frequencies is probably due to some experimental effects in edge sample production or differences in the edge gradient method as compared to the sinusoidal method. For example, processing time differences, the presence of harmonics, curve smoothing, and imaging procedures can all cause inaccuracies.

Figure 5-11 shows the color MTFs as determined from the neutral sample. It agrees with the theory of the Modulation Transfer Function for color materials in that the blue MTF is higher than the visual and the green which themselves are equal. The red MTF is lower than the other color MTFs. This is understandable considering light spread through the emulsion. The MTFs of the individual seperations are shown in Figure 5-12. They agree with the rank order of the

respective color MTFs in the neutral but are of a different magnitude. The fact that the experimental neutral MTF does not completely match the published MTF does not invalidate the comparison of the neutral's MTFs with those of the seperations.

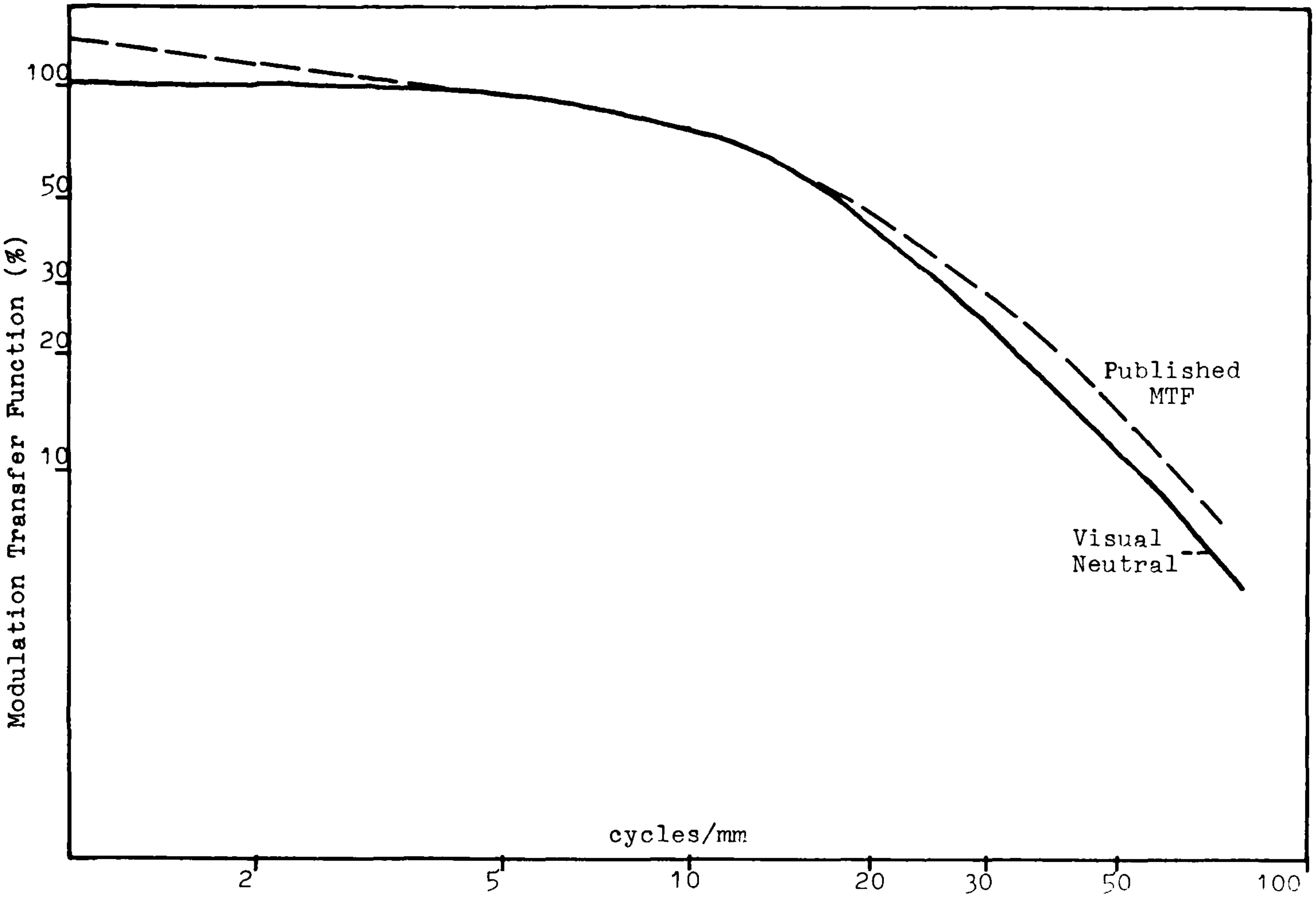

Fig. 5-10 MTFs - Visual vs Published

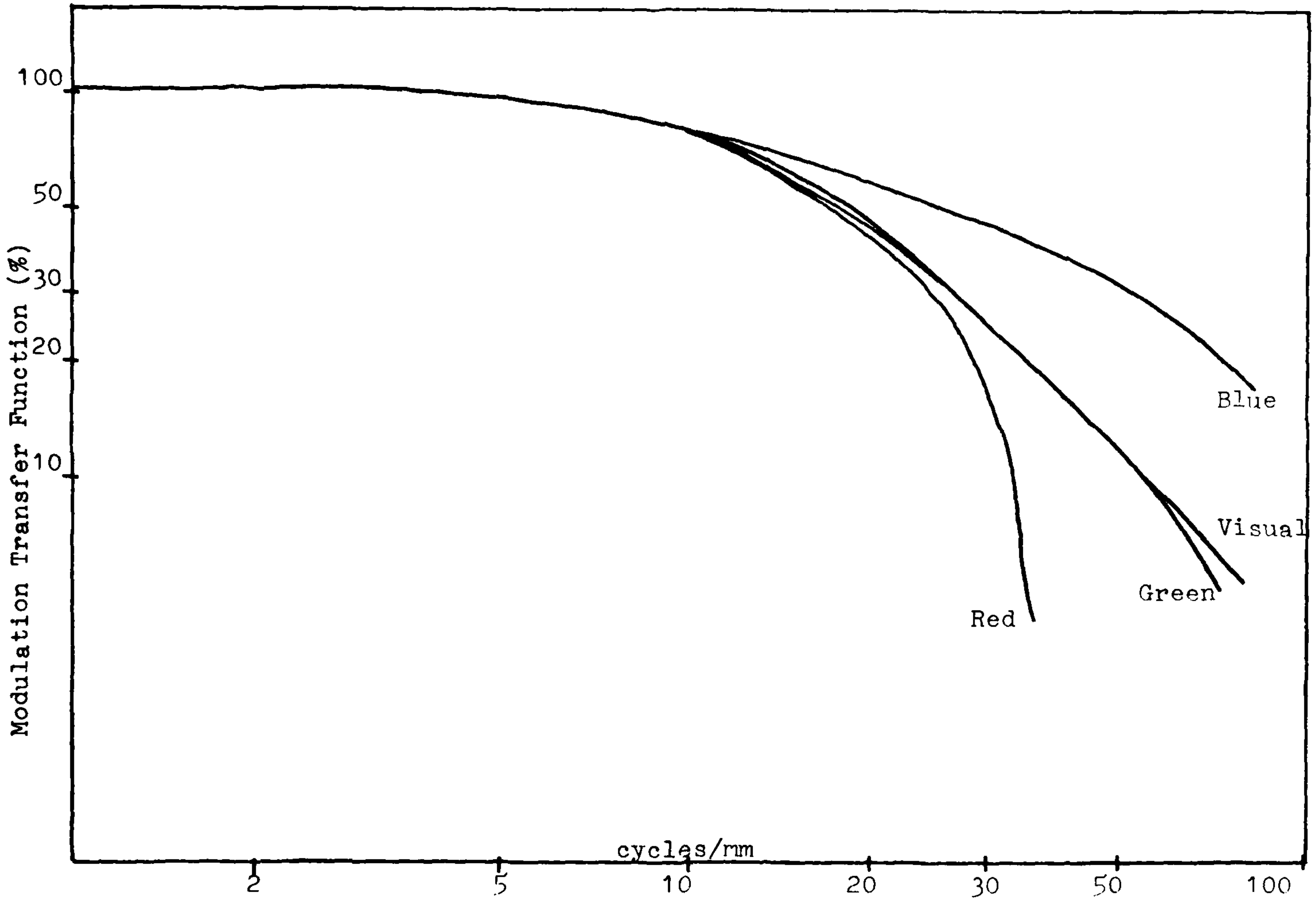

Fig. 5-11 MTFs - Neutral

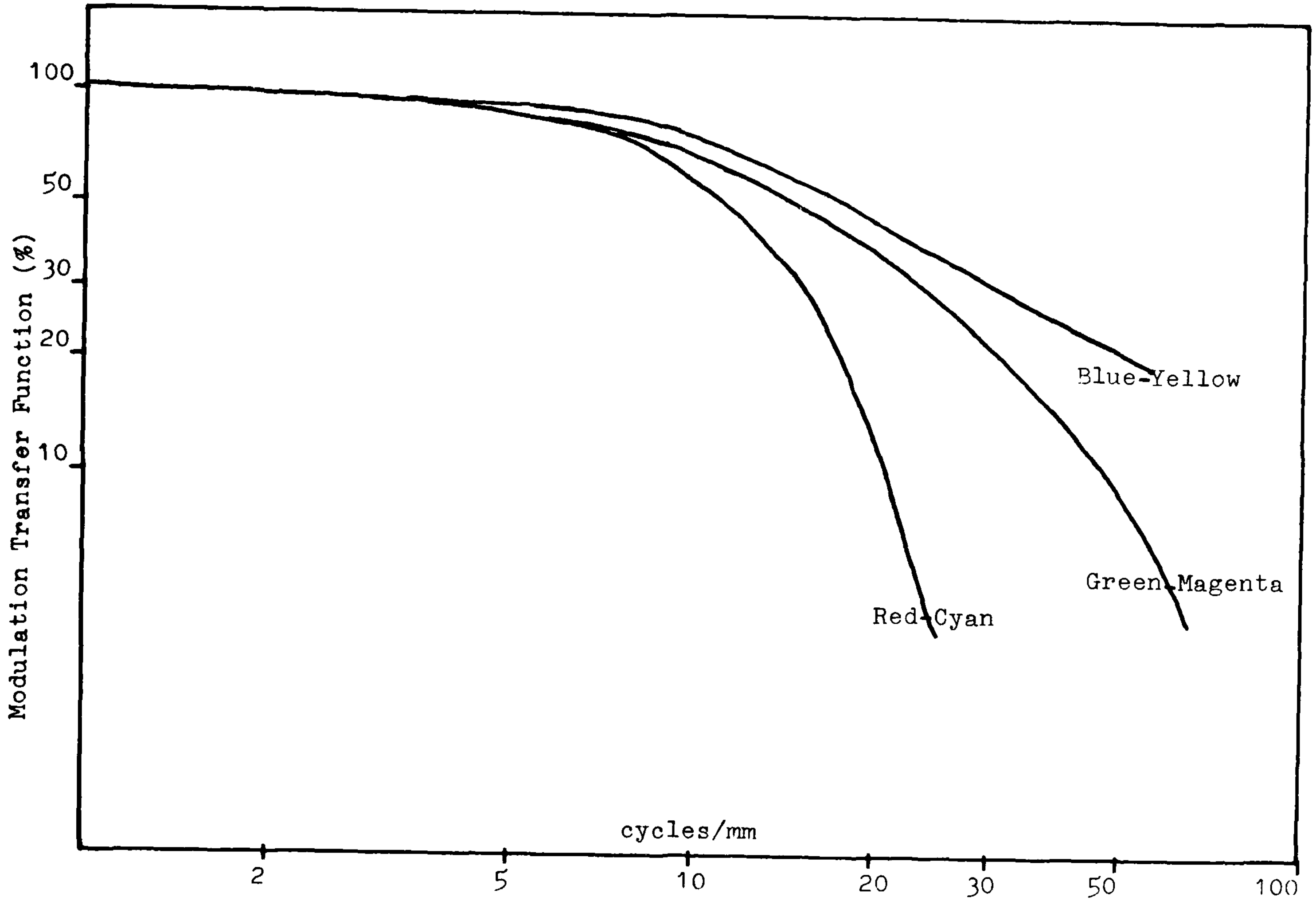

Fig. 5-12 MTFs - Seperations

ANALYSIS

The hypothesis of this study as stated previously is that interimage effects will be manifested through the effective MTF of a reversal material and to a different degree in any seperations which will be indicated by modified MTFs. The differences between the corresponding MTFs of the neutral sample and those of the seperations can be evaluated and will, in the absence of any experimental errors or effects, reveal differences attributable to interimage effects. In order to draw any conclusions about the extent of any interimage effects, it is necessary to first analyze the edge data.

The microdensitometer edge traces of the samples are shown in Figure 6-4 thru 6-10 and the normalized exposure edge curves used for the MTF program are shown in Appendix E. The comparison MTF curves are shown in Figure 6-1 thru 6-3 in log-log format. Careful study of the edge curves in terms of edge gradient analysis allows the MTF curves to become predictable and consistent with that obtained by the MTF computer program. In the case of the neutral sample, the edge traces reveal certain significant characteristics. The slope of the straight line portions of the edge traces are relatively equal for the visual, green, and red and decrease

ir that order. The blue trace is significantly higher in slope than the others. This is consistent with the edge traces of the target edge shown in Appendix E which again shows the blue as being steeper with the others approximately equal. Inclusion of the sensitometric response of the layers in the analysis results in the exposure edge curves shown in Appendix E which were used in the MTF program. Locking at the exposure edges and their width between points of negligable slope, the curves are all about equal with the red being slightly wider. Considering that the spread function is obtained by differentiation of the effective exposure edge, a wider edge trace gives a wider spread function and indicates a greater diffusion of the illumination within the layer. So far, the analysis would indicate that the blue layer should have the highest MTF with the red layer MTF somewhat less than the others. Further comparison of the straight line portions and the shoulders of the exposure edge curves shows that the shoulder of the blue curve is the least definitive. Some of this is due to the edge target since the trace of the target edge is noisy. Some of the noise could have been eliminated by smoothing of the exposure edge itself rather than just the edge trace. It is clear that the red-neutral has the widest spread function and the blue-neutral the narrowest. This results in the blue layer showing the highest MTF and the red layer the lowest. Therefore, the MTF values of the traces on the

neutral are consistent with the MTF theory mentioned previously. Final MTF values represented by the curves in this chapter and chapter 5 account for some of the effect of the edge target and the microdensitometer. In other words, the final MTF values are the result of dividing out the MTFs of the edge target itself.

The edge data of the color samples can also be analyzed in the same manner. The blue seperation again has the highest slope of the straight line portion with the green next followed by the red. Width of the exposure edge curves show the blue-yellow trace to be the narrowest with the red-cyan slightly wider than the green. Since the blue trace was the narrowest exposure edge and has the steepest slope, it is logical that the yellow seperation has the highest MTF. Comparison of the other two exposure edge plots shows the final MTF values are higher for the magenta seperation than the cyan. This is all apparent when looking at the spread functions which increase in width in the order blue-yellow, green-magenta, and red-cyan.

The comparison MTF curves between the layers of the neutral and the corresponding layers of the color samples shown in Figure 6-1 thru 6-3 can be confirmed in the same manner by analysis of the data. The red MTF of the neutral is higher than that of the cyan seperation; the green MTF of the neutral is slightly higher than that of the magenta seperation; and, the blue MTF of the neutral is higher than

that of the yellow seperation.

It would be expected if the hypothesis were valid that the neutral color MTFs would be either higher or lower than the MTFs of the seperations. This is true and is consistent for all comparisons. Considering the absence of any degradation in the analysis due to the film samples, microdensitometry, hand processing of the edge data or some combination of these, the differences between the same color MTFs would be due to emulsion characteristics and development effects.

The fact that the visual MTF determined in this study agrees favorably with the published curve indicates that the edge gradient and experimental techniques utilized were accurate and that results are correct. Thus, conclusions can be made about the MTF values for the layers and the differences can be attributed to interimage effects.

Other than thickness, emulsion characteristics which could cause any significant differences in the MTFs are restricted to granularity and the dyes used. The color of the exposing rediation considerably affects the emulsion MTF. Fast emulsions of large grain size quickly absorb blue light and scatter the red which diffuses farther. Thus the MTF is best for the blue and worst for the red. On the other hand, fine grained emulsions have small grain size and strongly scatter blue light while transmitting red light. This results in the MTF being higher for red (or green) light than

for blue and differences increase with spatial frequency. However, Ektachrome 160 has both fast and slow layers so its MTFs should agree with the characteristics of fast emulsions which they do. From the results of the neutral sample, it appears that the manufacturer has not made any significant changes in granularity of the red layer to compensate for its position on the bottom of the emulsion.

The spectral absorption of the dyes could have some effect on the microdensitometry of the blue and green layers in the neutral but should not have any effect on the seperations. For instance, the microdensitometer readings on the green layer in the neutral could be picking up some response from the red layer and the blue layer. This effect would not be present in the seperations since only one color of dye is present. The red layer in the neutral is also practically unaffected by the dye absorption of the blue and green layers. Therefore, spectral absorption of the dyes could account for some of the MTF differences between the respective color layers.

There can also be some interimage effects caused by development that could modify the edge images and account for differences between the MTFs of the seperations and their corresponding color MTF in the neutral sample. The study by Meissnee "...indicated that under normal processing conditions interimage effects were mainly brought about by diffusion of the iodide ions from the top to the bottom

layer....and also considerably enhanced by the addition of bromoiodide to the underlayer."[1] Without knowledge of the emulsion characteristics other than layer order and the published data, it is difficult to identify any development mechanisms causing interimage effects. However, the respective MTF differences between the neutral sample and the seperations indicates that interimage are present.

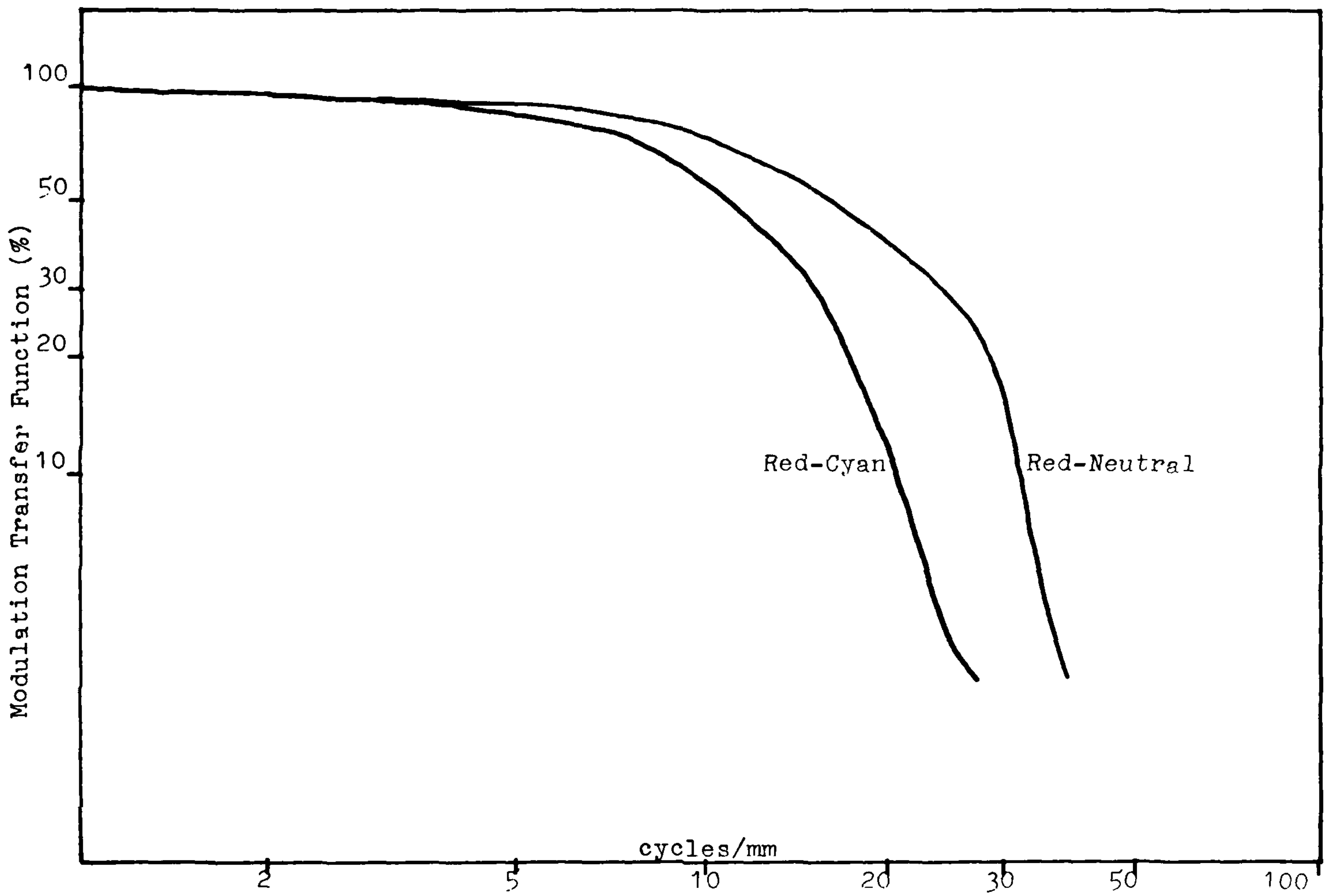

Fig. 6-1 MTF - Red-Neutral vs Red-Cyan

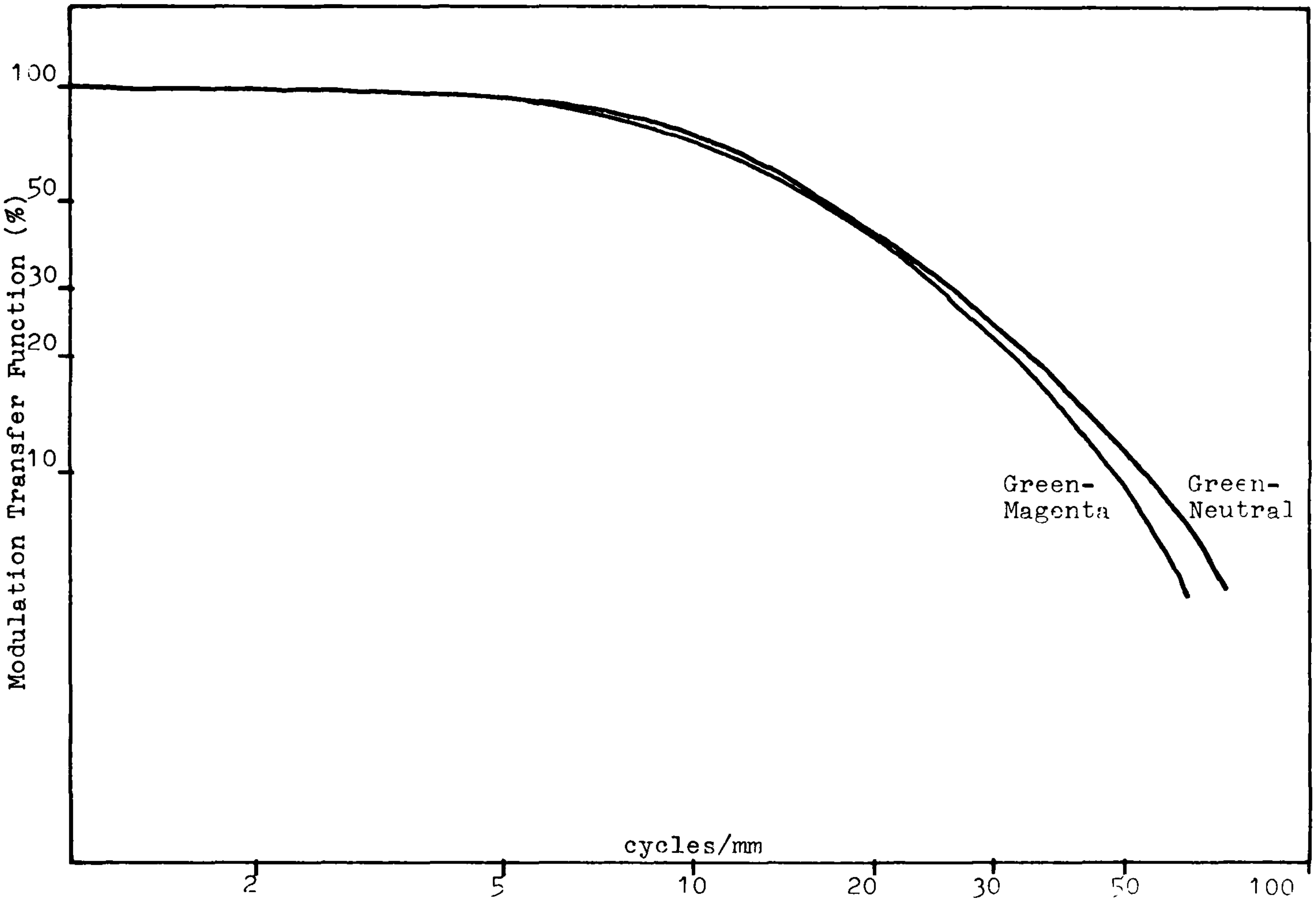

Fig. 6-2 MTF - Green-Neutral vs Green-Magenta

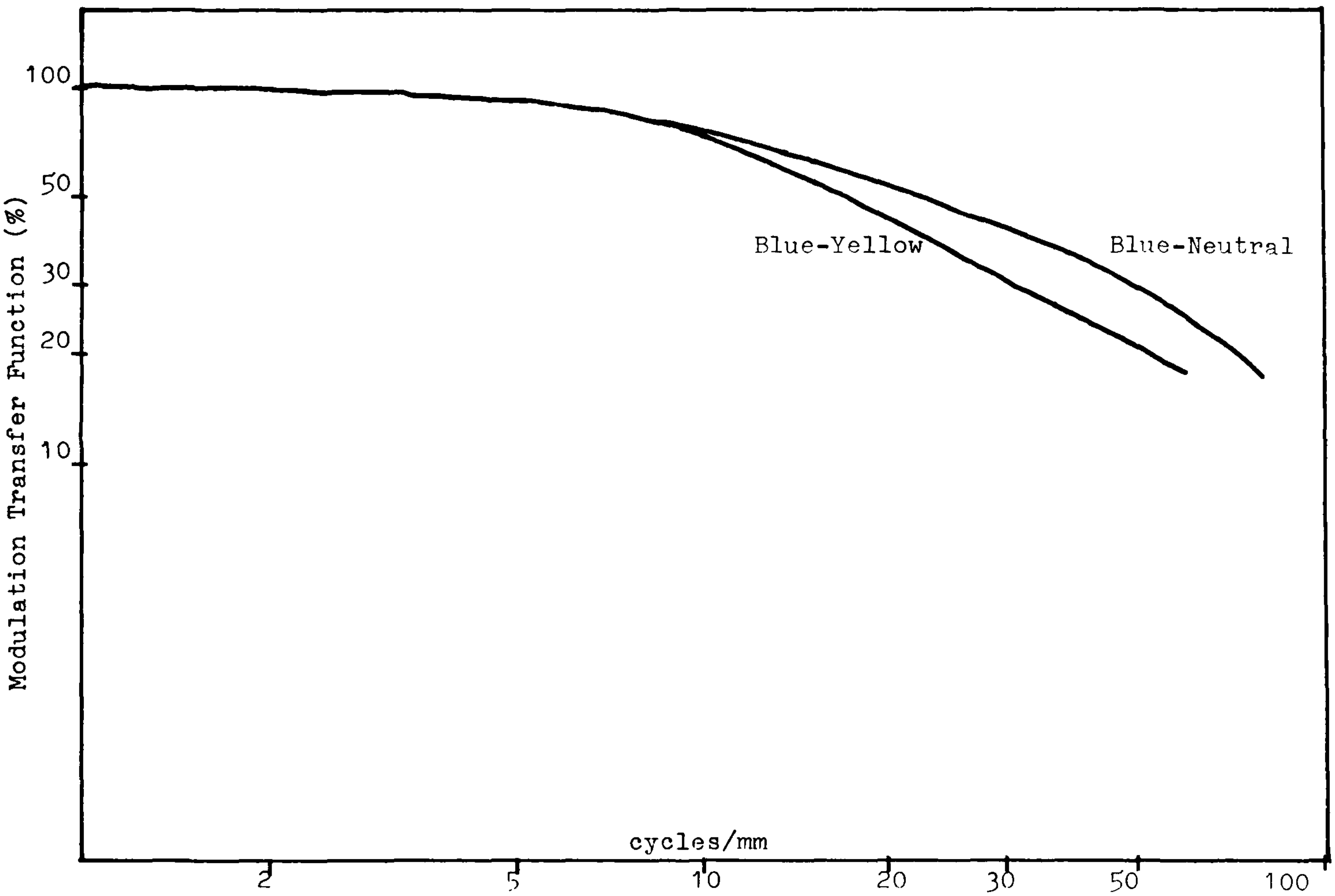

Fig. 6-3 MTF - Blue-Neutral vs Blue-Yellow

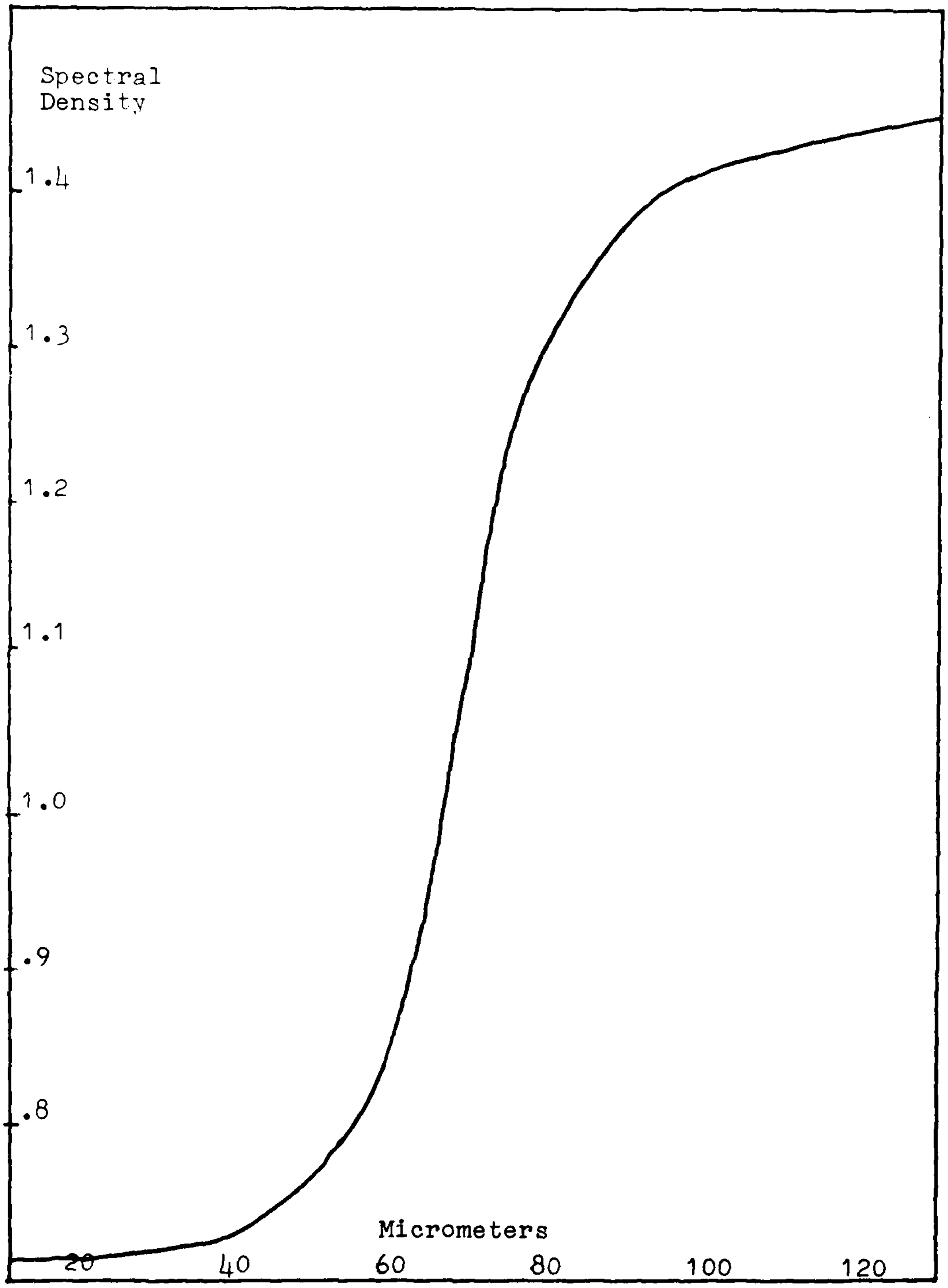

Figure 6-4. Visual-Neutral Edge Trace

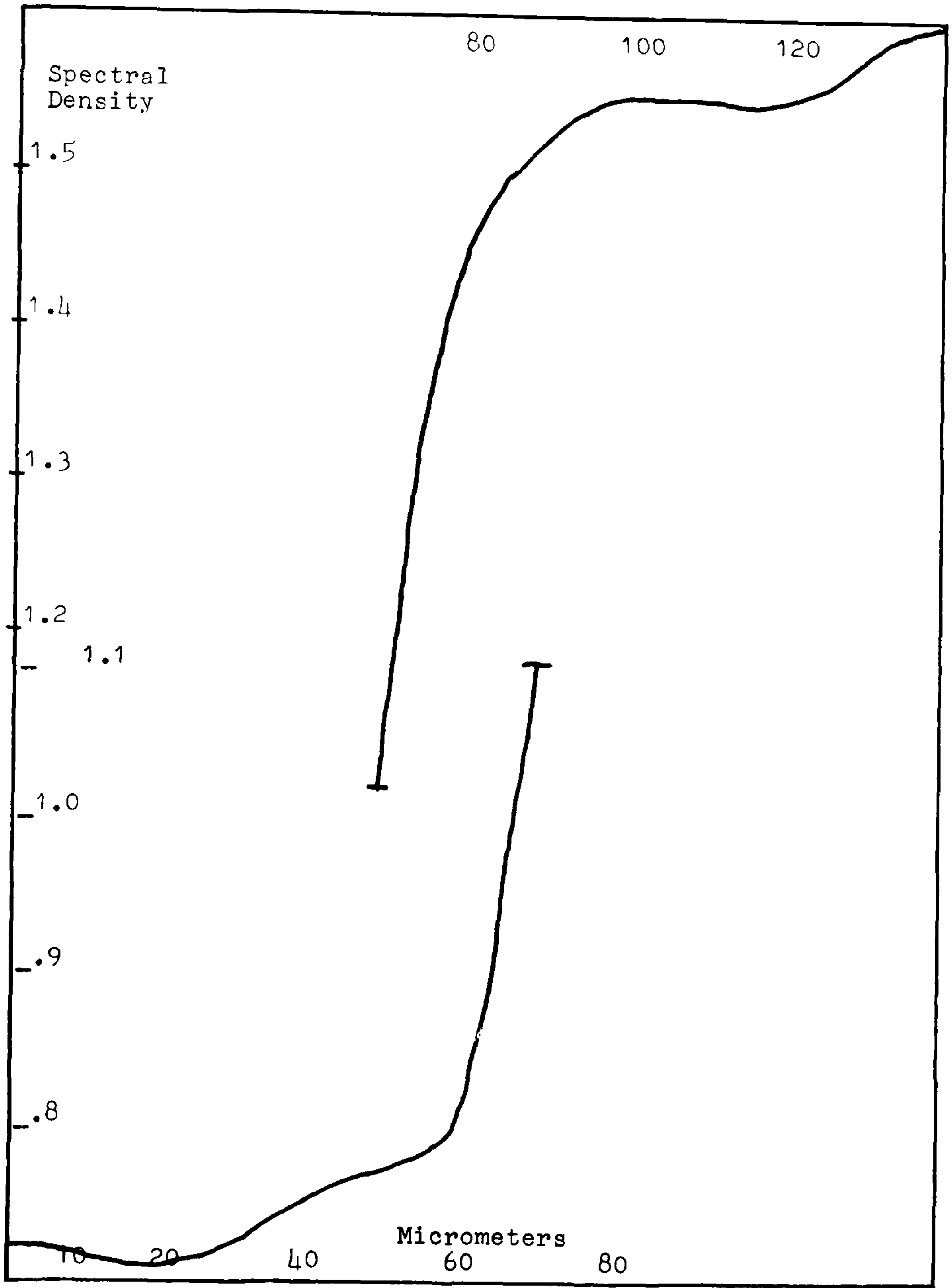

Figure 6-5. Blue-Neutral Edge Trace

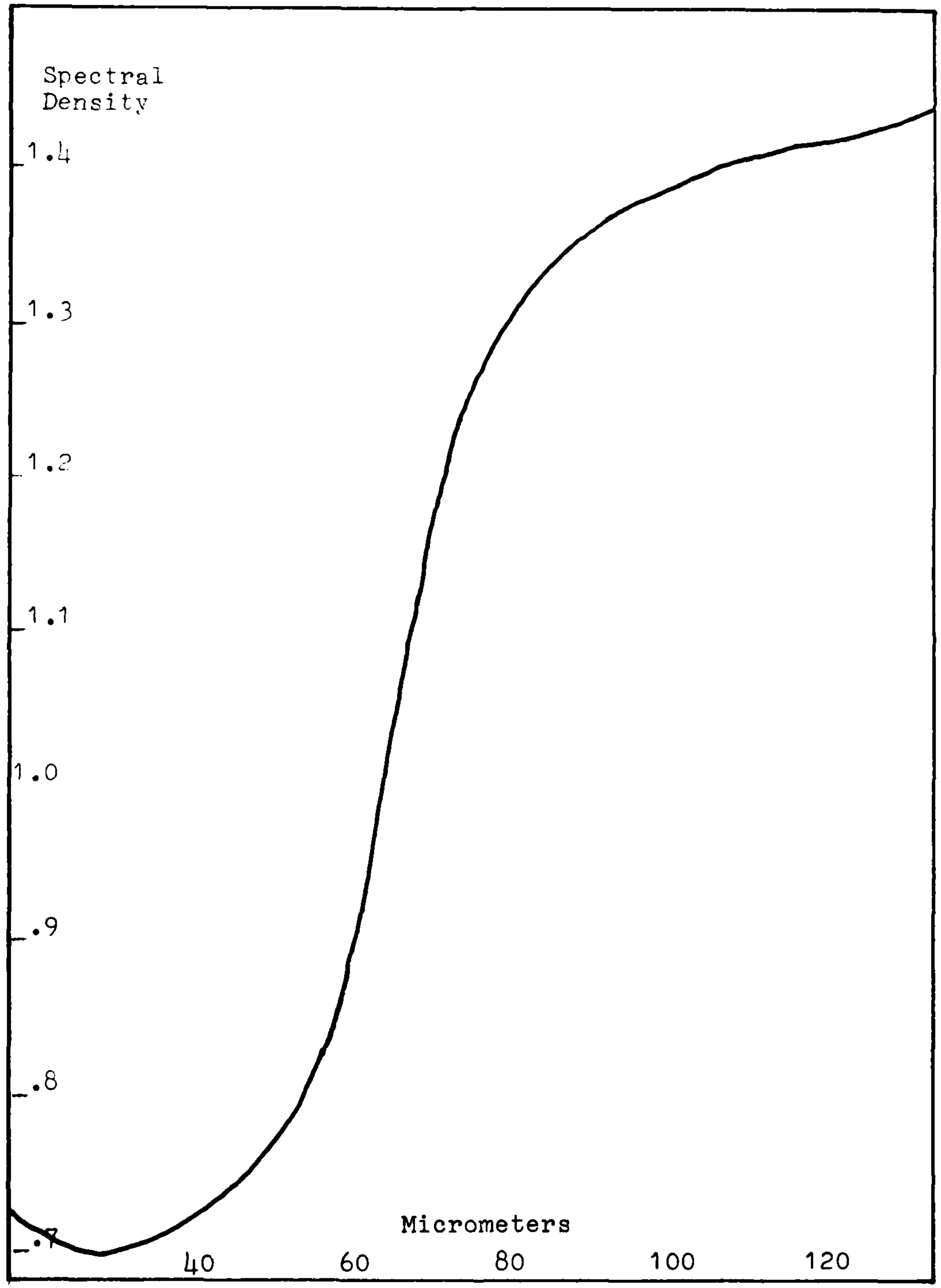

Figure 6-6. Green-Neutral Edge Trace

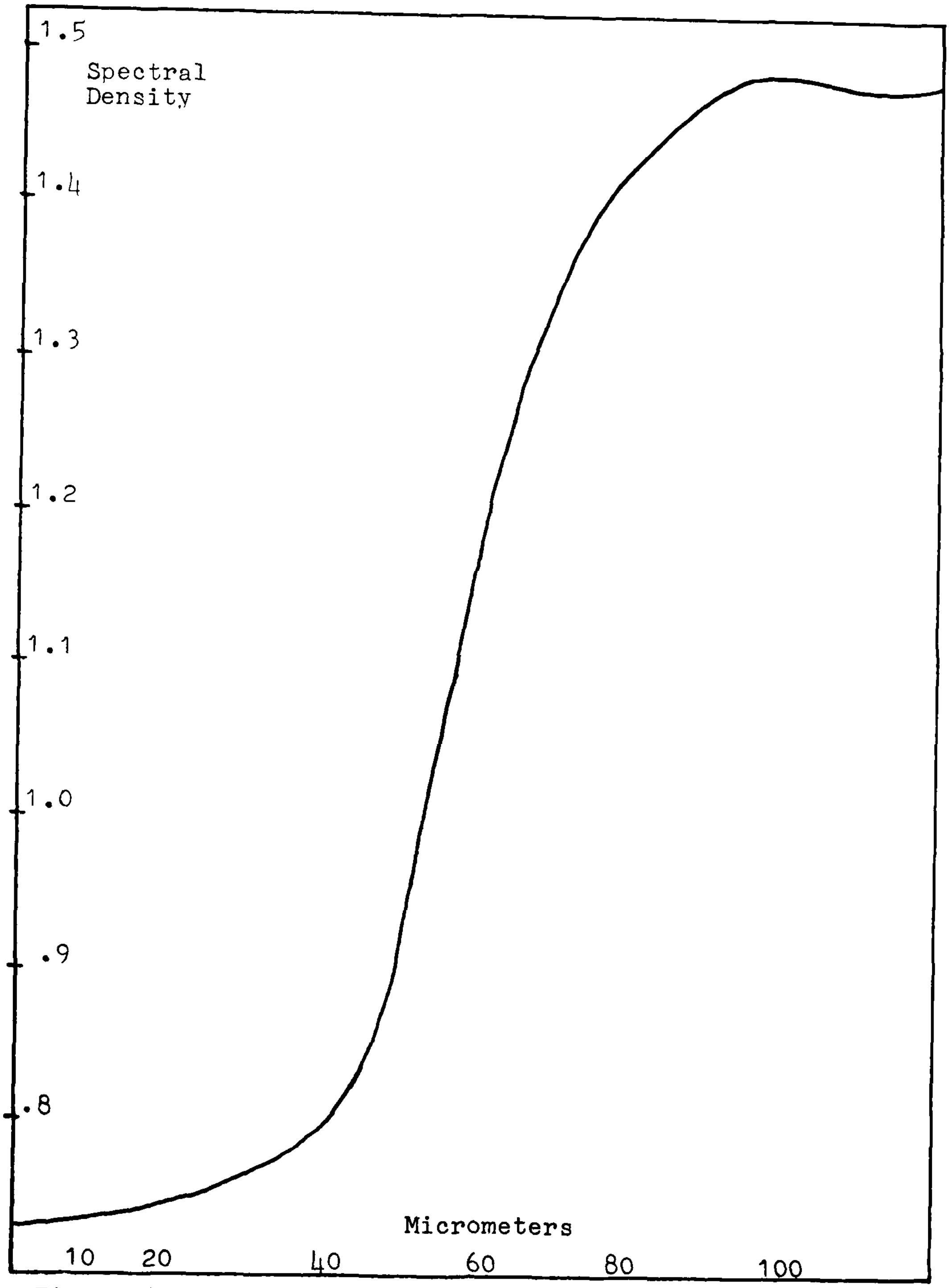

Figure 6-7. Red-Neutral Edge Trace

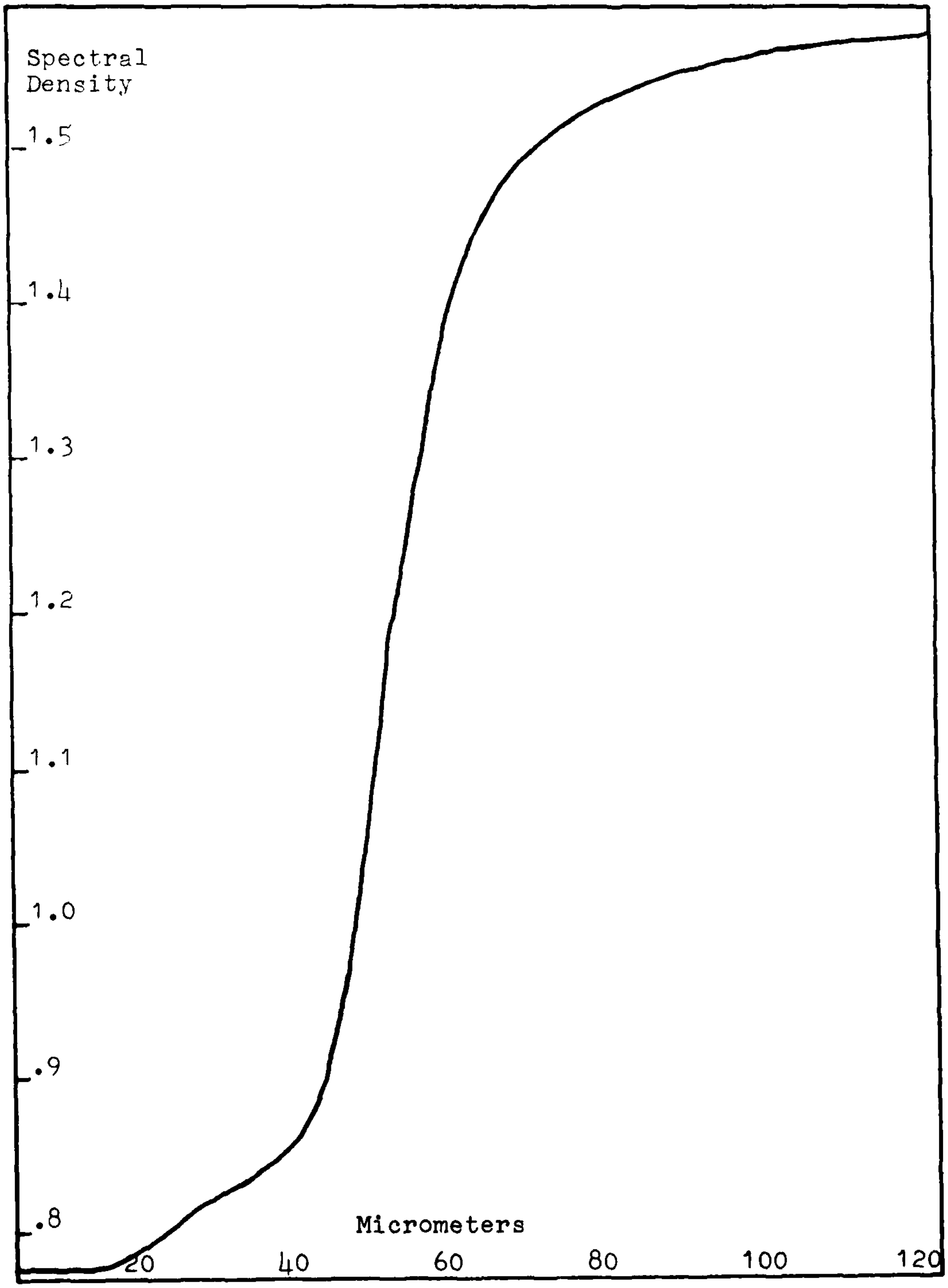

Figure 6-8. Blue-Yellow Edge Trace

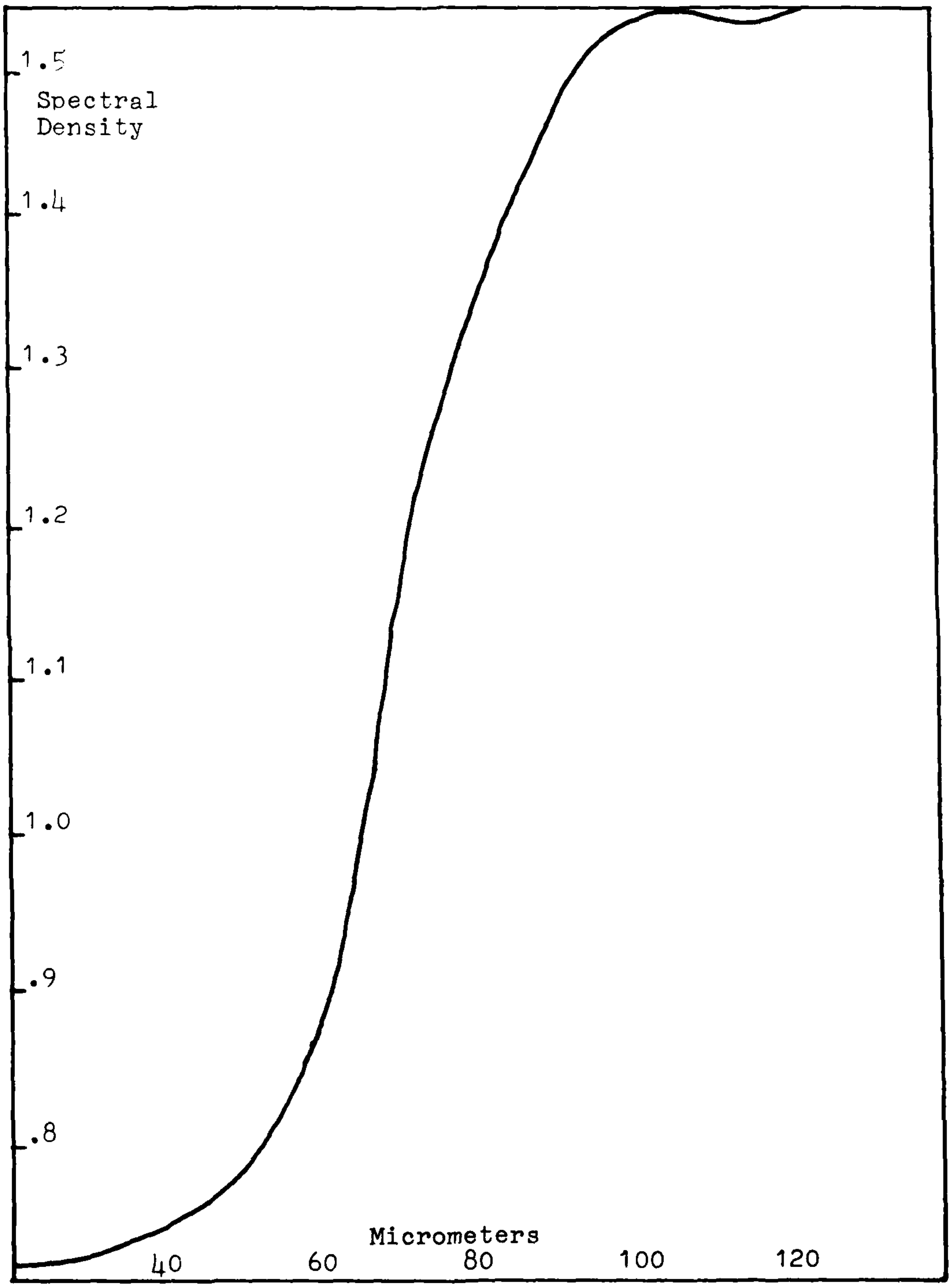

Figure 6-9. Green-Magenta Edge Trace

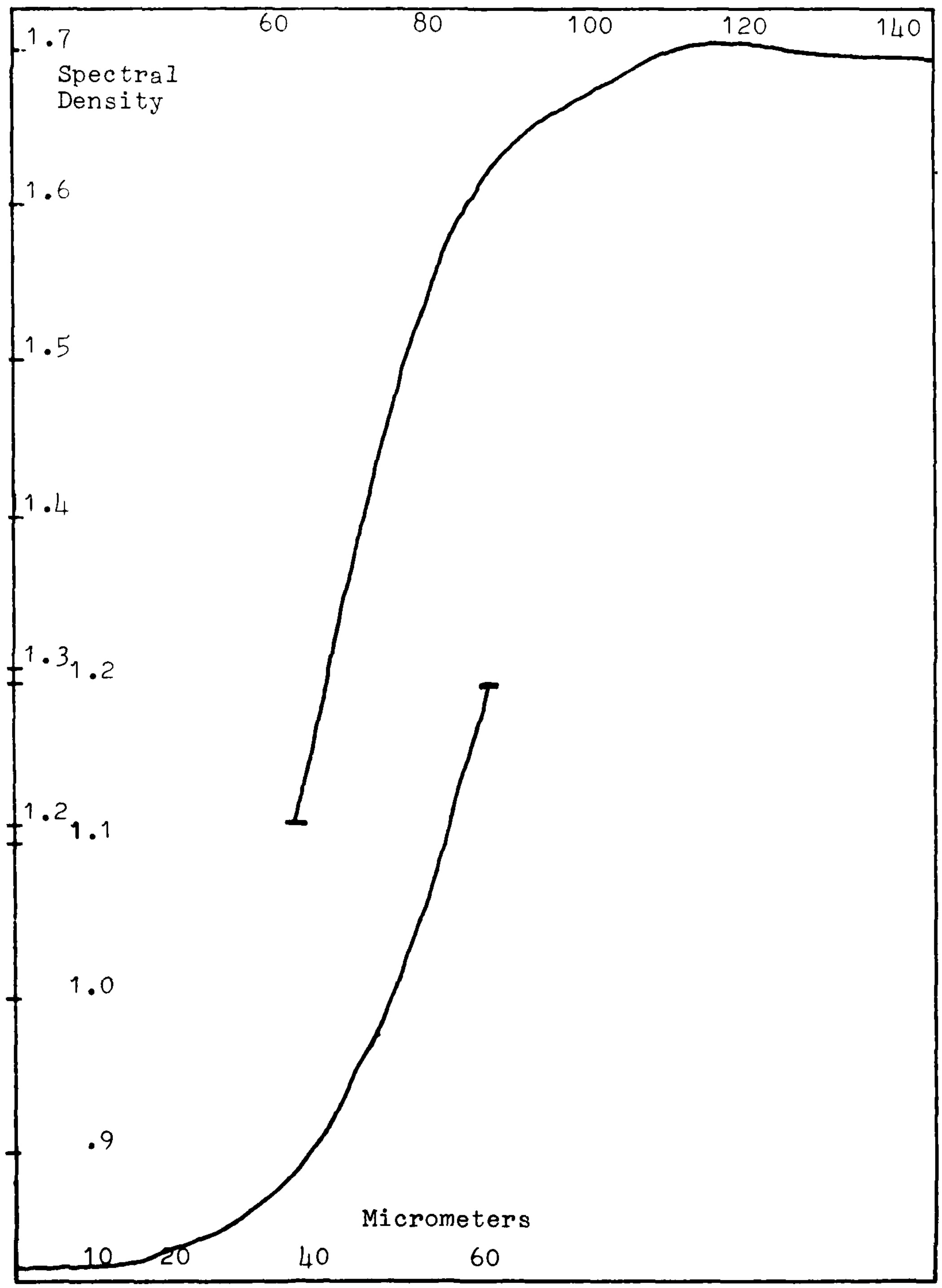

Figure 6-10. Red-Cyan Edge Trace

FOOTNOTES FOR CHAPTER 6

[1] H. D. Meissnee, "On the Mechanism of Interimage Effects," Photographic Science and Engineering, vol. 13, no. 3, May-June, 1969, p. 141.

CONCLUSION

This study has shown that the color MTFs in a colorimetric neutral and those in a comparable neutral formed by three seperations are not equal. Differences, which are indicated by lower MTF values at higher frequencies in the seperations, must be attributed to some interlayer or interimage effect which is dependent on development activity or dye formation. From the results obtained in this study, it can be stated that interimage effects are manifested in the Modulation Transfer Function of Kodak Ektachrome 160 Professional Film.

Results of this study also show the significant reduction in the MTF as emulsion thickness increases and as dye is reduced in adjacent layers. This is especially evident in the red layers. This can be important to aerial imagery and the choice of film especially when imaging predominantly complementary colored scenes where the results of this study indicate a reduction in spatial reproduction at higher frequencies. Perhaps manufacturers should also publish the MTF curves for each color seperation. The differences in MTFs between the layers and the presence of interimage effects could be used to improve spatial frequency response of an emulsion.

Although this study indicates the manifestation of interimage effects, it is only a preliminary analysis and further study should be performed. This could be done for different density levels and with various dye layer combinations. Both edge and sinusoidal images could be analyzed and replication would allow statistical evaluation. This could lead to some quantification of interimage effects. This study does, however, indicate strongly that interimage effects on the MTF of a color reversal material are present and may be quite significant. The results of this study demonstrate the importance of MTFs for each layer and also the importance of measuring a specified color image. Use of an image other than neutral for MTF measurements could result in erroneous values due to interimage effects and the unequal MTFs of the layers. It is apparent that a standard is needed for measurement of MTFs of color materials which incorporates color specification and color MTFs. The method utilized in this study would be suitable.

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APPENDIX A

Calculation of CIE Chromaticity Coordinates

Calculation of CIE Chromaticity Coordinates

X, Y, Z	CIE Tristimulus Values
E	Relative Energy of D_{5000}
T	Transmittance from Spectrophotometer Trace
$\bar{x}$, $\bar{y}$, $\bar{z}$	Tristimulus values of the equal energy spectrum

$$X = \int_{400}^{700} \bar{x}(\lambda)E(\lambda)T(\lambda)d\lambda$$

$$Y = \int_{400}^{700} \bar{y}(\lambda)E(\lambda)T(\lambda)d\lambda$$

$$Z = \int_{400}^{700} \bar{z}(\lambda)E(\lambda)T(\lambda)d\lambda$$

** λ = wavelength

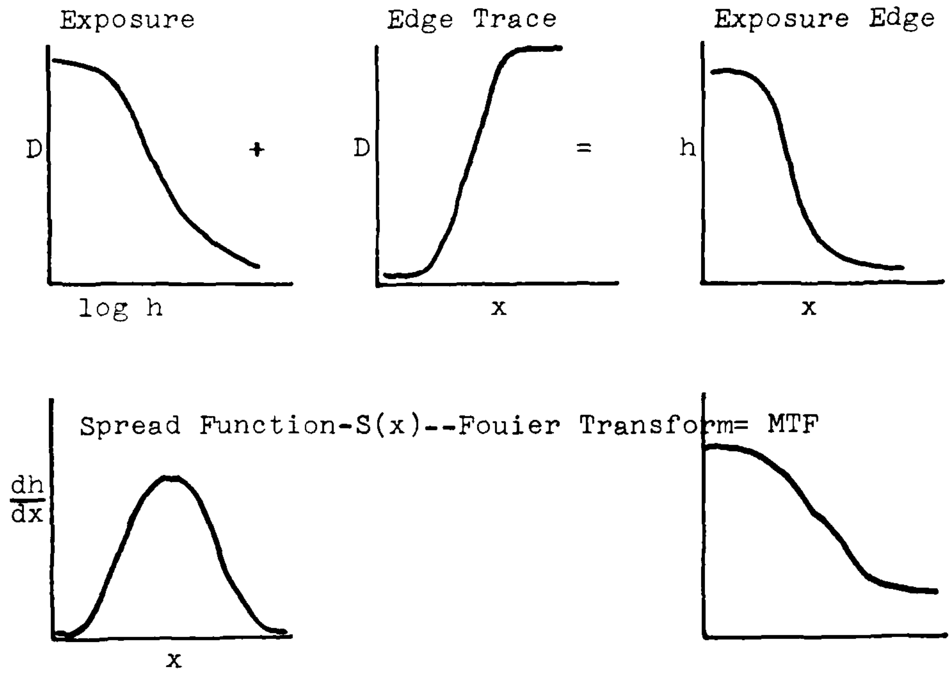
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z}$$

x,y = chromaticity coordinates

APPENDIX B

Edge Gradient Method of MTF Calculation

EDGE GRADIENT METHOD OF MTF CALCULATION

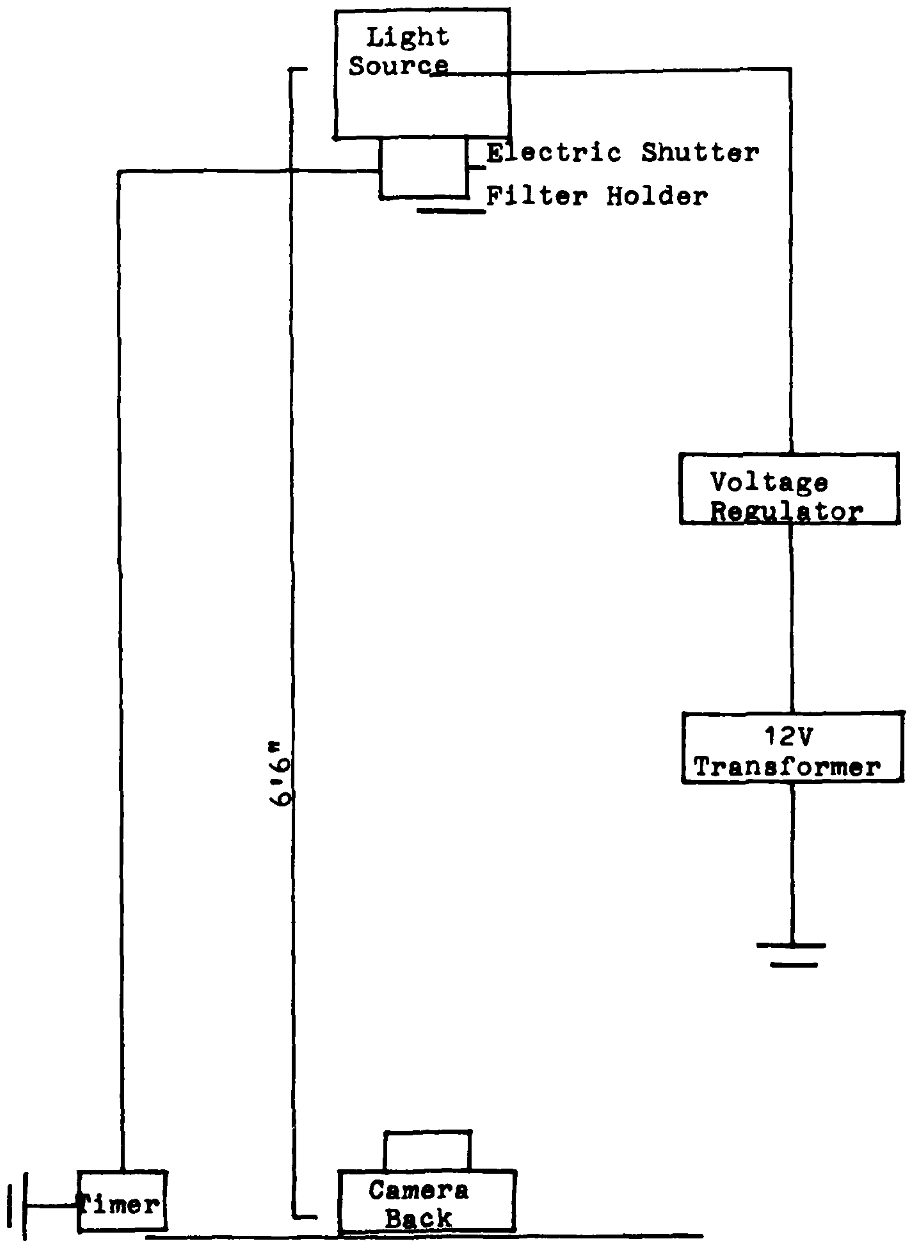


The resulting MTF is that for the system. To obtain the MTF of the film, the system MTF was divided by the MTF of the microdensitometer.

APPENDIX C

Exposure Apparatus

Exposure Apparatus



APPENDIX D

MTF Computer Program

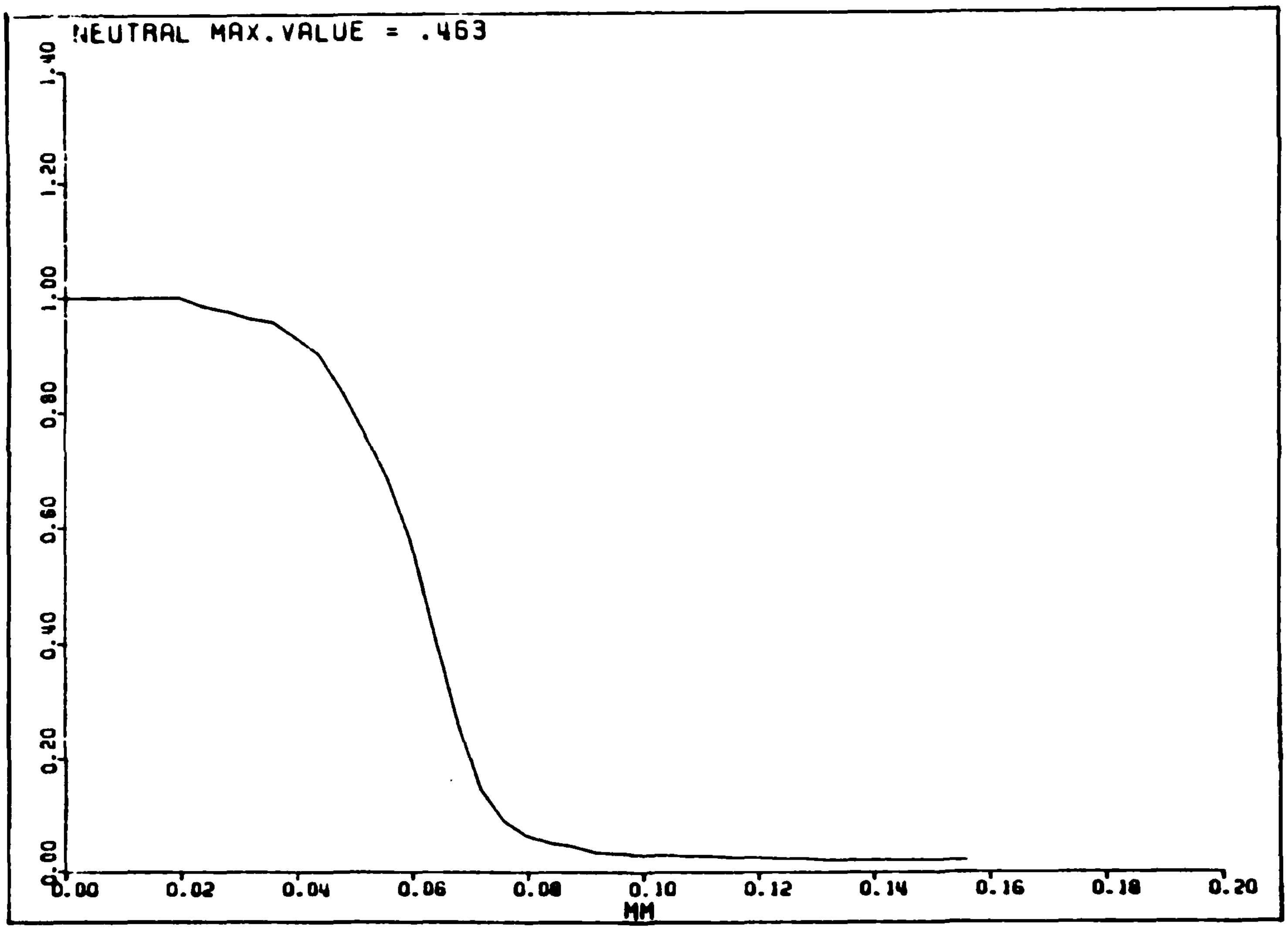
MTF COMPUTER PROGRAM

```
C FILENAME:  EGAJS
C EDGE MTF CALCULATION-- JJJ 8/77
C SET F:1/INPUT EDGE REFLECTANCE PROFILE
C SET F:2/OUTPUT SPREAD FUNCTION
C SET F:3/OUTPUT MTF
C RUN EGAJB,JPLOTB,FOURG.F;L.TEK,L.GRF   OVER EGAJL
      REAL DATA(2060),RTRANS(2,2048),SHAW(2,2048),F(2050)
      INTEGER  LABEL (16)
      CALL BELL
      CALL SPLOT
      NARRIN=2048
C READ DATA FILE
200   READ(1,109,END=333) PTSPMM,SLTWTH,SNOISE,JJJ
      NT=64
      IF(SLTWTH.LE.0.0001)NT=-NT
      READ(1,100)NPTS,LABEL
      IF(NPTS.GT.NARRIN)STOP'NPTS MAX.=2048 JJJ'
      READ(1,101)(DATA(I),I=1,NPTS)
C PLOT REFLECTANCE PROFILE OF EDGE
      Do 1 I=1,NPTS
1     F(I)=FLOAT(I-1)/PTSPMM
      CALL CALPTL(NPTS,F,DATA,'MM',2,
      1 'REFLECTANCE',11,LABEL,NT)
      CALL HOME
      N1=NPTS-1
C SKIP TAKING DERIVATIVE IF JJJ=-1
      IFF(JJJ.EQ.-1) GO TO 201
      DO 10 I=1,N1
      I1=I+1
      DATA(I)=DATA(I1)-DATA(I)
10    CONTINUE
      DATA(NPTS)=0
C OUTPUT SPREAD FUNCTION PROFILE
      WRITE(2,109)PTSPMM,SLTWTH,SNOISE
      WRITE(2,100)NPTS,LABEL
      WRITE(2,103)(DATA(J),J=1,NPTS)
C FIND MAX AVERGING OVER 3 PTS.
201   DSTO=DATA(1)+DATA(2)+DATA(3)
      DMAX=ABS(DSTO)
      DO 11 I=3,N1
      I1=I=1
      IM2=I-2
      DSTO=DSTO=DATA(I1)-DATA(IM2)
      IF(ABS(DSTO).LE.DMAX)GO TO 11
      DMAX=ABS(DSTO)
      IMAX=I
11    CONTINUE
```

```
      DMAS=DMAX/3
      WRITE(108,105) LABEL
      WRITE(108,102)DMAX,FLOAT(IMAX)/PTSPMM
C     PERIOD(PER)   IS TWICE MAX PTS.FROM CENTER TO ENDS,
C     WHERE CENTER IN MAX. DERIVATIVE PT.
      IFREQ=MAXO((NPTS-IMAX),IMAX)
      IFREQ1=IFREQ=1
      PER=2*IFREQ;IPER=PER=.5
      JL=IFREQ-IMAX=1
      JH=JL=NPTS-1
      TWOPI=2.*3.1415926535
      DO 20 J=1,IPER
20    RTRANS(1,J)=RTRANS(2,J)=0
      DO 21 I=JL,JH
      POS=IFREQ-I
C  HANNING WINDOW (RAISED COSINE), UNITY AREA
      RTRANS(1,I)=DATA(I-JL=1)*(1.+1.*COS(POS*TWOPI/PER))
21    CONTINUE
C FOURIER TRANSFORM , NORMALIZE BY MTF(0)=1 & CORRECT FOR
      MD APERTURE
1000  CALL FOURG(RTRANS,IPER,-1,SHAW)
      DO=SQRT(RTRANS(1,1)**2+RTRANS92,1)**2)
      DATA(!)=1
      DO 30 I=2,IFREQ1
      F(I) = FLOAT(I-1)*PTSPMM/(2.*FLOAT(IFREQ))
      DATA(I)=SQRT(RTRANS(1,I)**2+RTRANS(2,I)**2)/DO
 C CORRECT FOR MICRODENSITOMETER APERTURE
      IF(SLTWTH.LE.0.0001)GOTO 30
      PIX + TWOPI*F(I)*SLTWTH/2
      SLCF=SIN(PIX)/PIX
      IF(SLCF.LT..25)SLCF=.25
      DATA(I)=DATA(I)/SLCF
30    CONTINUE
C  OUTPUT TTY PLOT
      CALL JPLOT(IFREQ1,DATA,F,-1)
C  PLOT MTF
        CALL CALPTL(IFREQ1,F,DATA,'FREQUENCY(CYCLES/MM)',
      1  'MTF",3,LABEL,NT)
      WRITE(3,109) PTSPMM,SLTWTH,SNOISE
      WRITE(3,100) IFREQ1, LABEL
      WRITE(3,103) (DATA(J),J=1,IFREQ1)
      GO TO 200
333   CALL EPLOT
      CALL EXIT
100   FORMAT(I,16A4)
101   FORMAT(32F4.3)
102   FORMAT(//'MAXIMUM IS ',E.4,'AT ',F.3,'MM')
103   FORMAT(7E.4)
105   FORMAT(16A4)
109   FORMAT(3E.4,I)
      END
```

APPENDIX E

Edges, Spread Functions, and MTFs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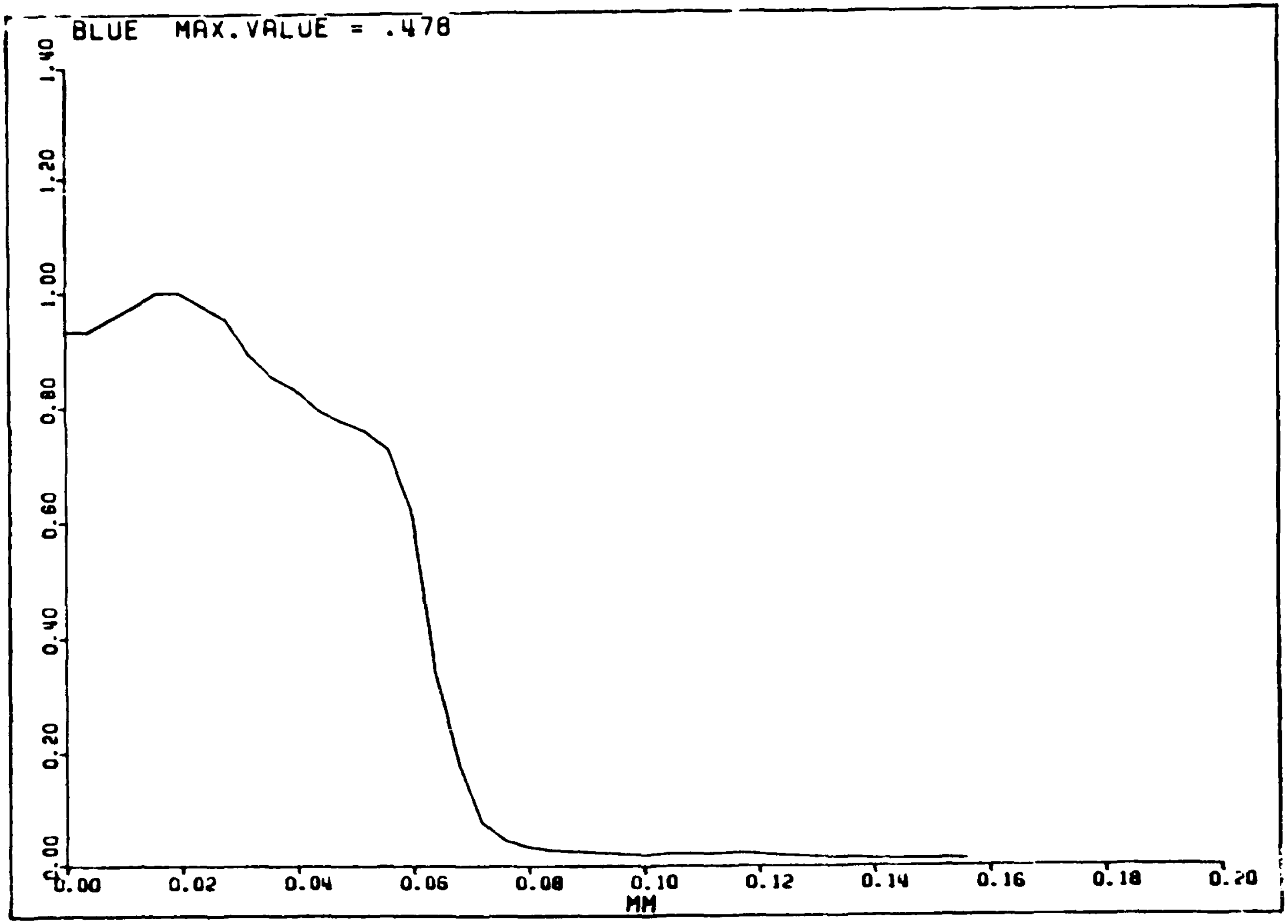

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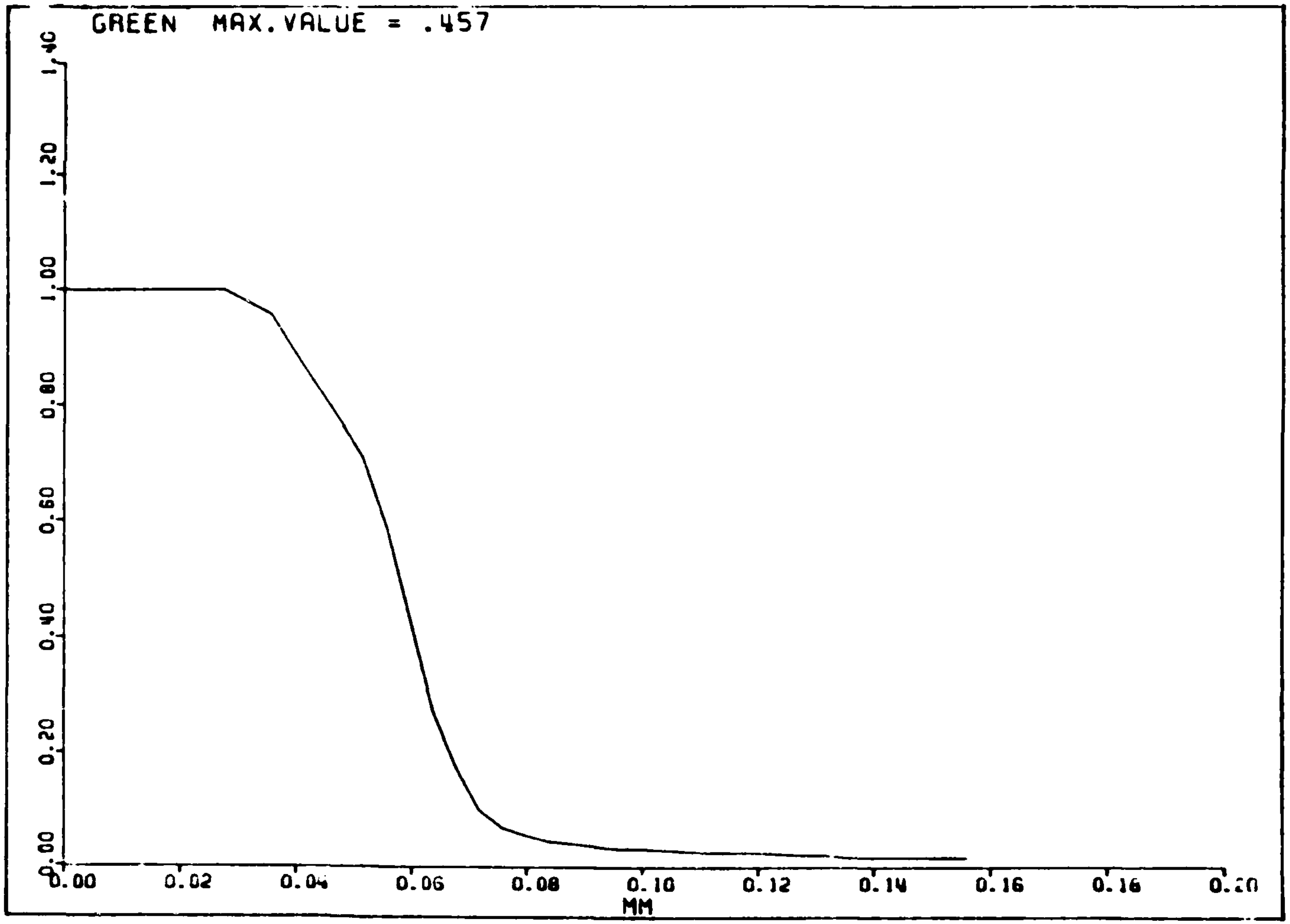

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0.12
0.14
0.16
0.16
MM

AD-A105 399 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 14/5
INTERIMAGE EFFECTS AND THE MTF OF A COLOR REVERSAL FILM.(U)
JUL 78 J D PANNING
UNCLASSIFIED AFIT-CI-79-253T NL

2 of 2
AD
A105399

END
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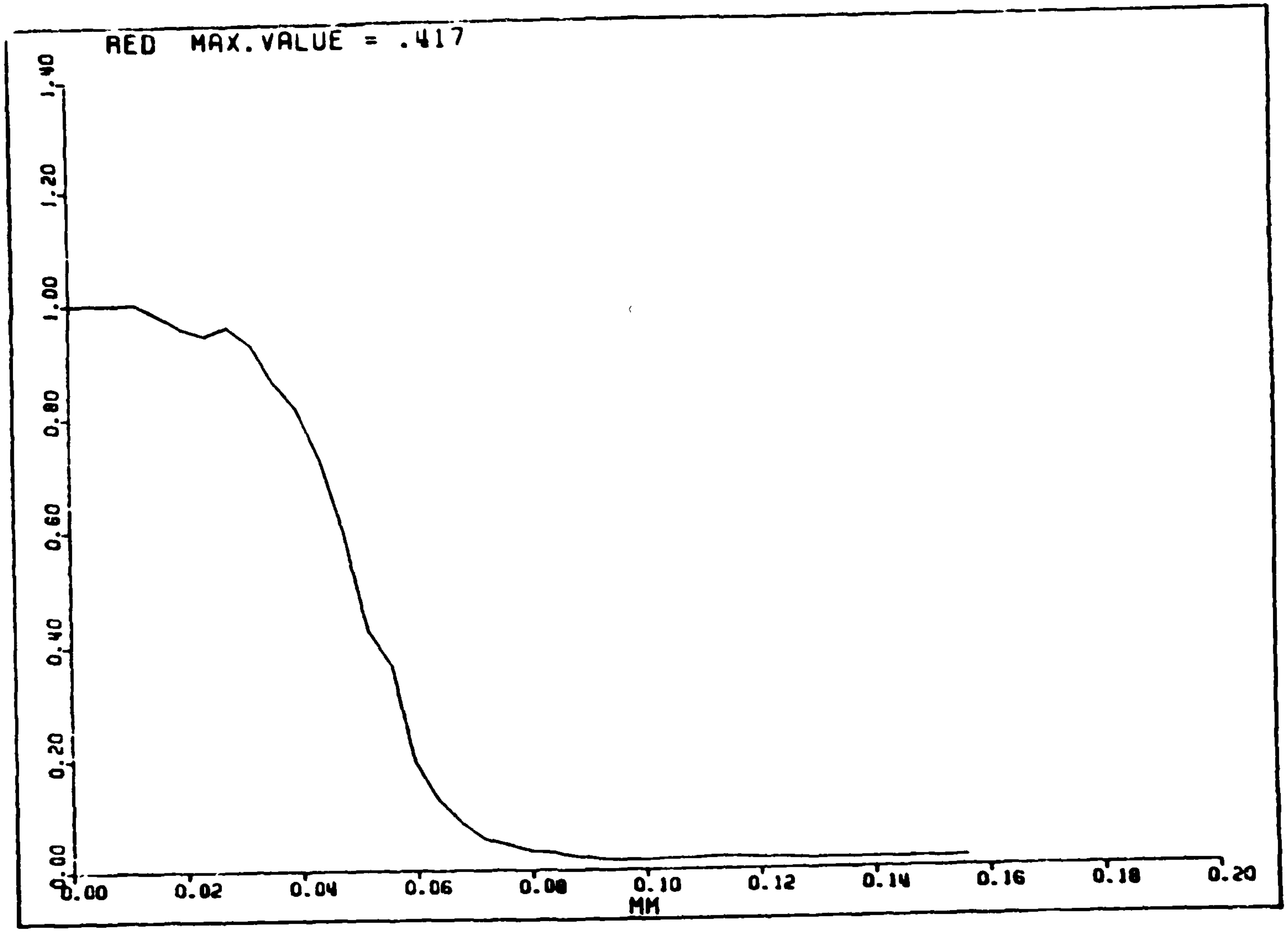
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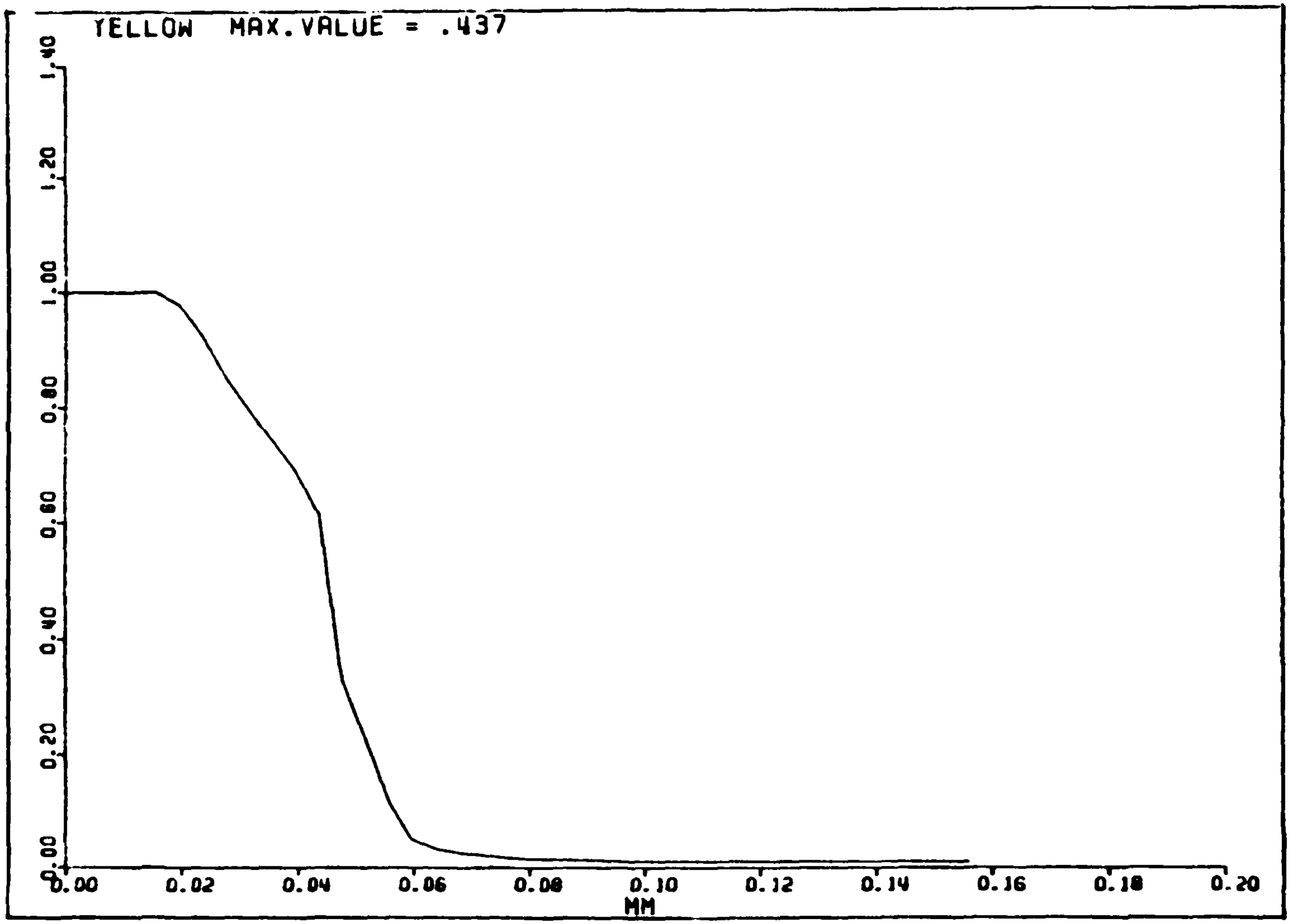

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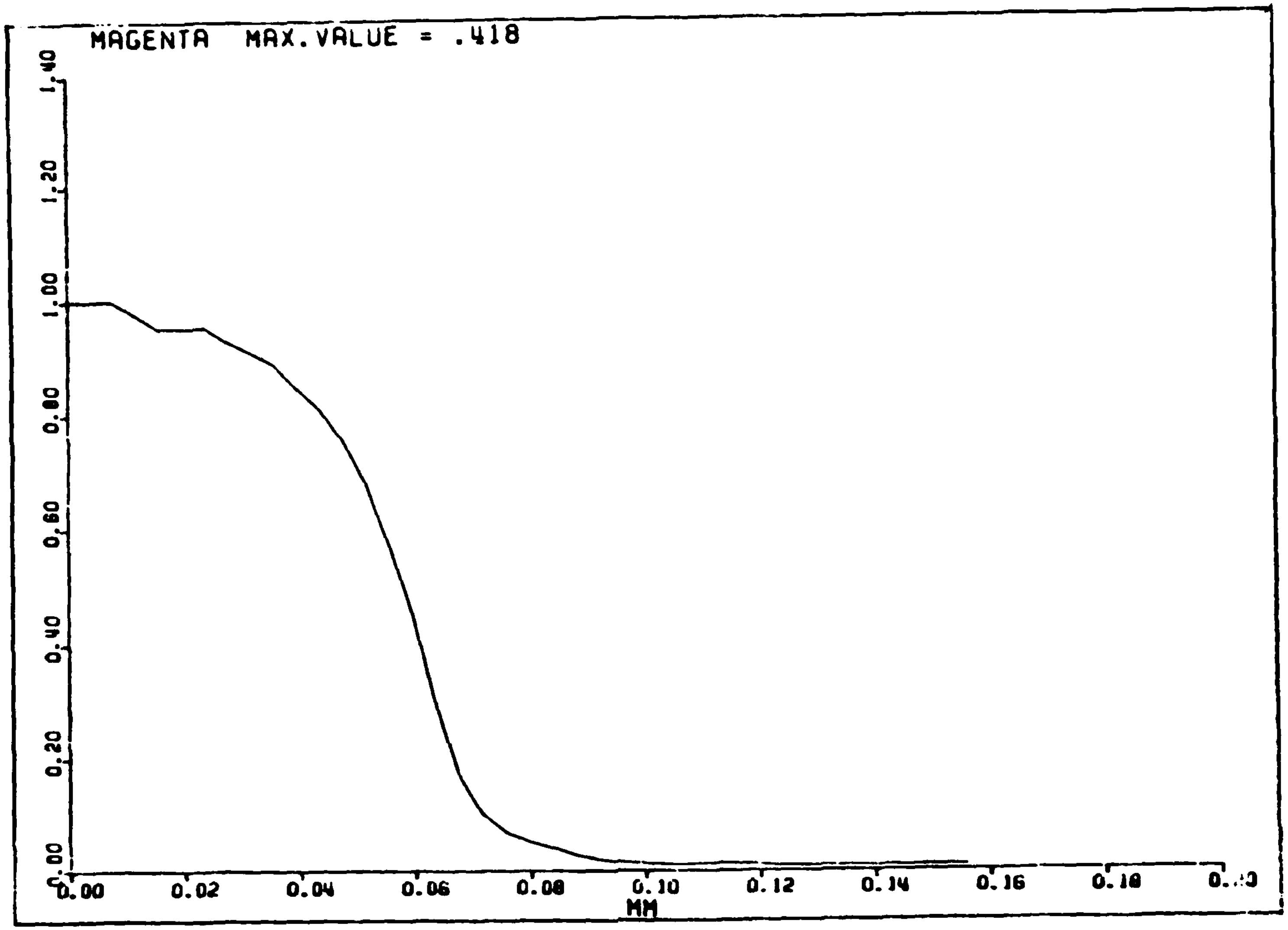

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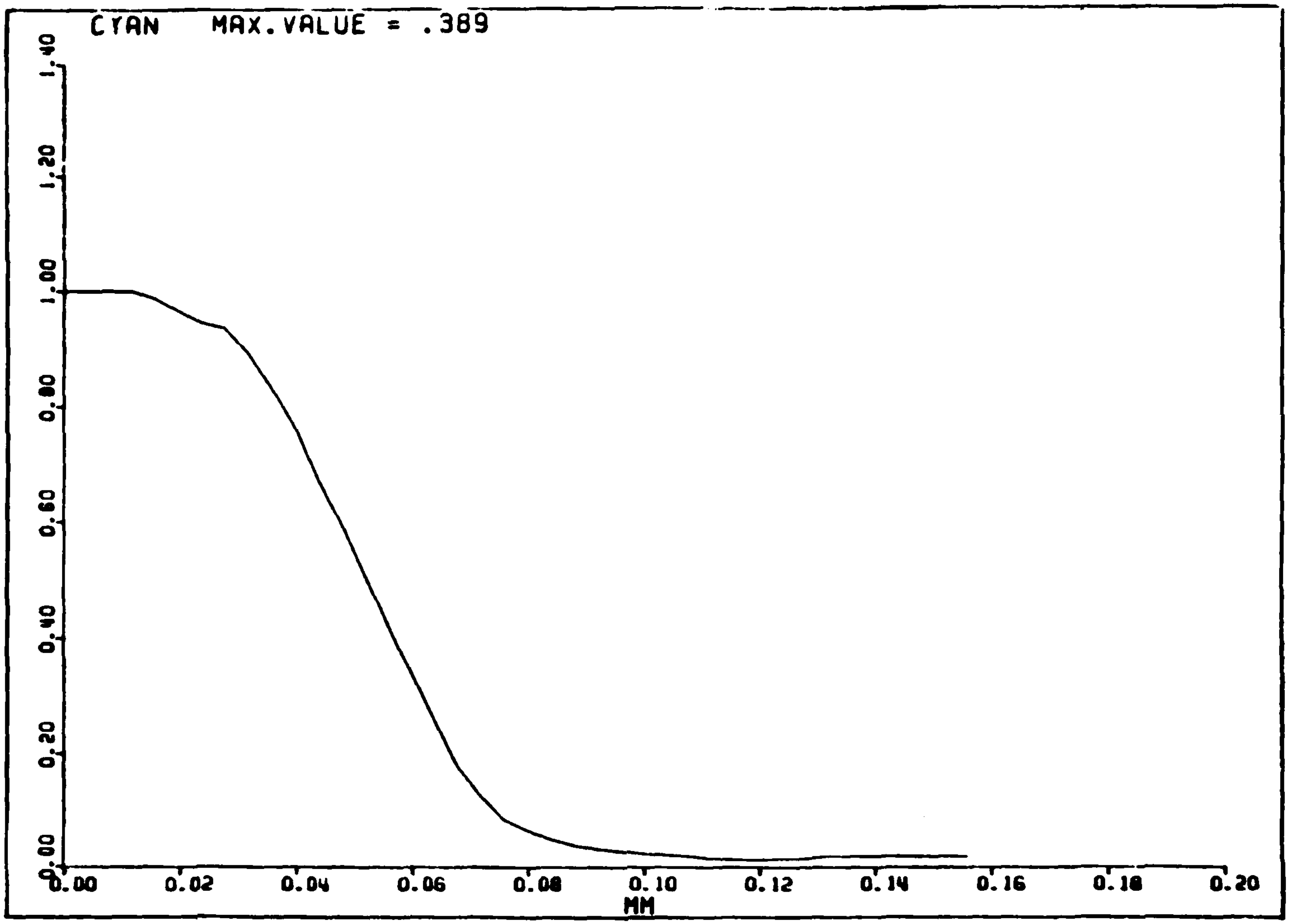
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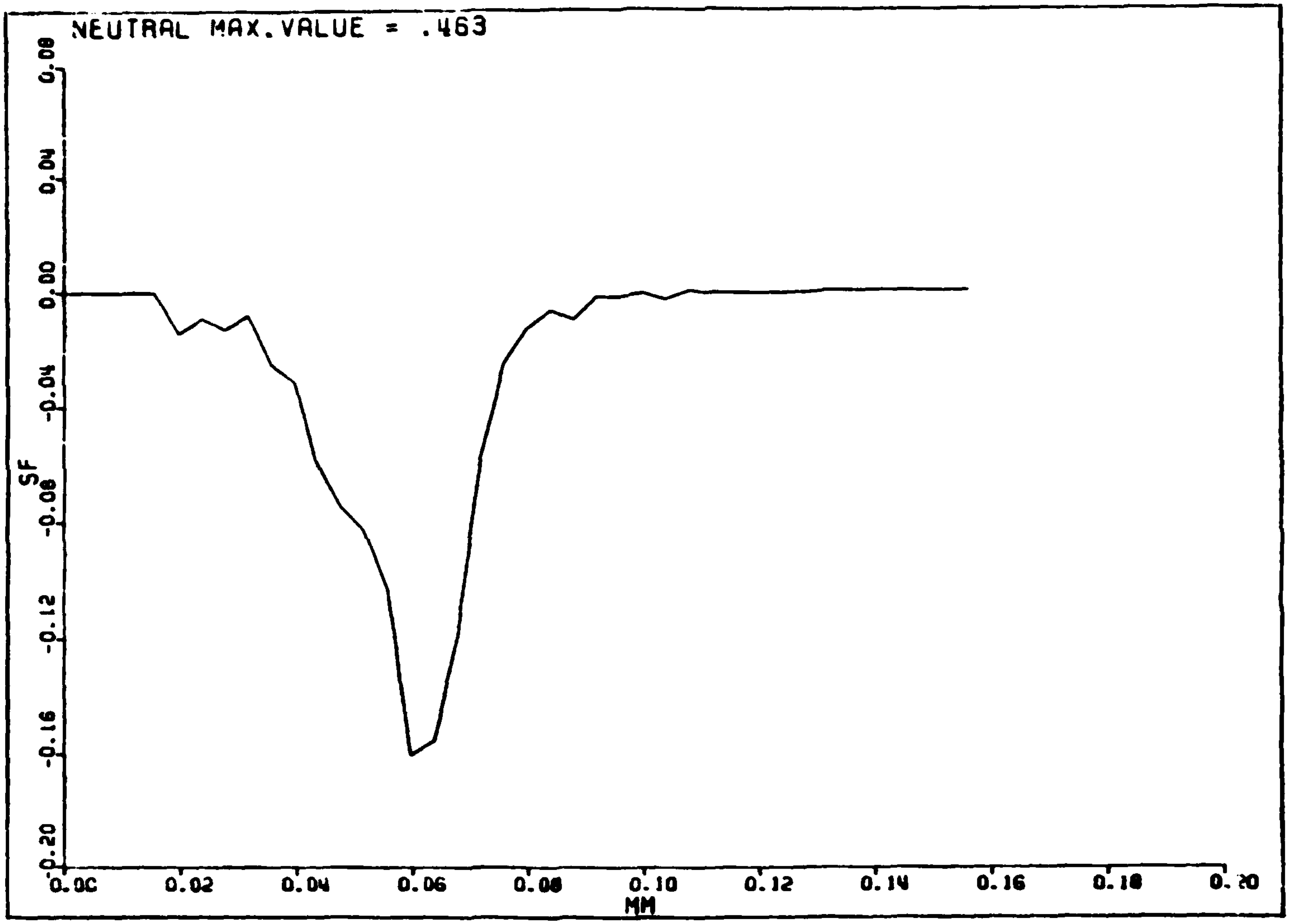

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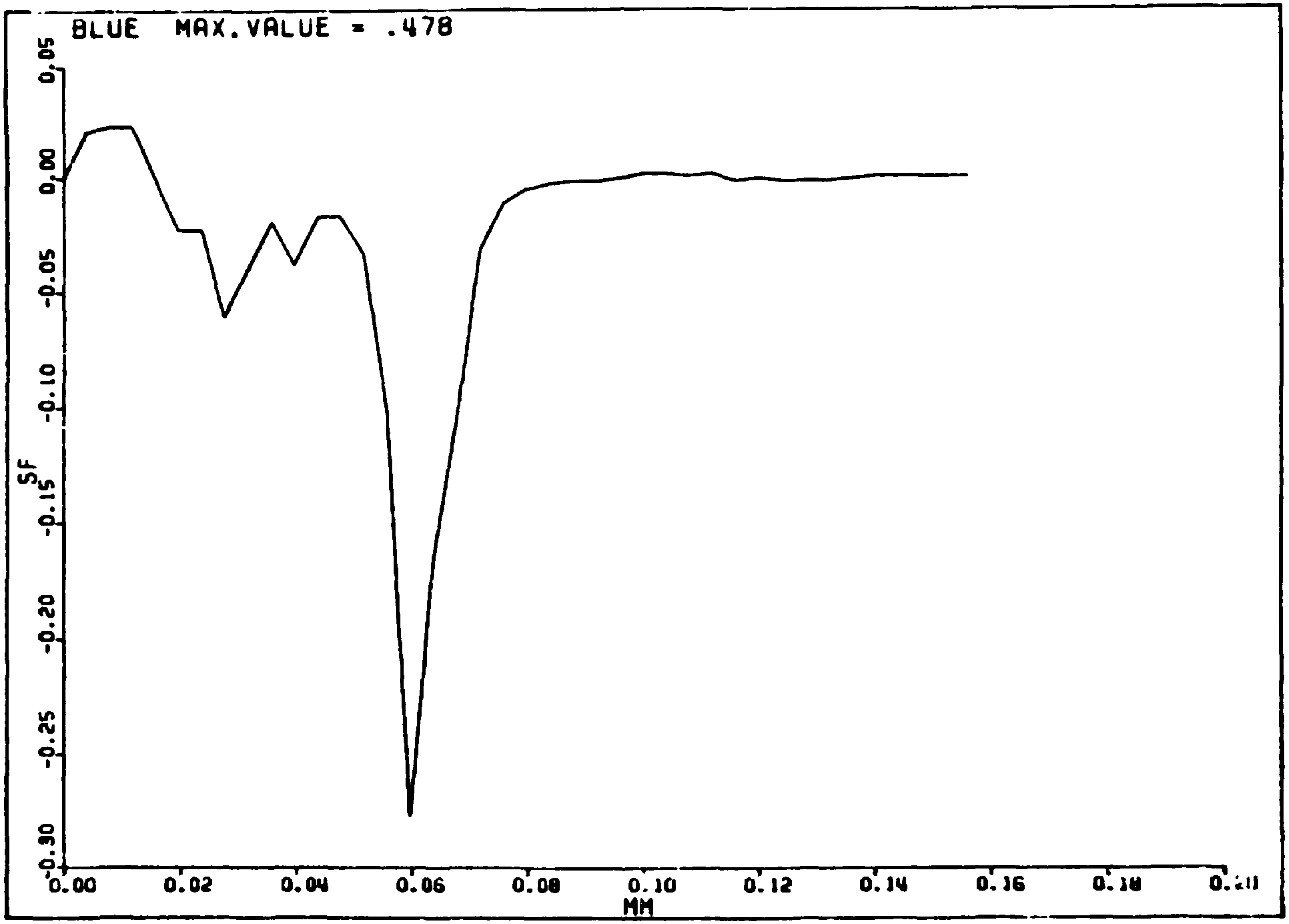
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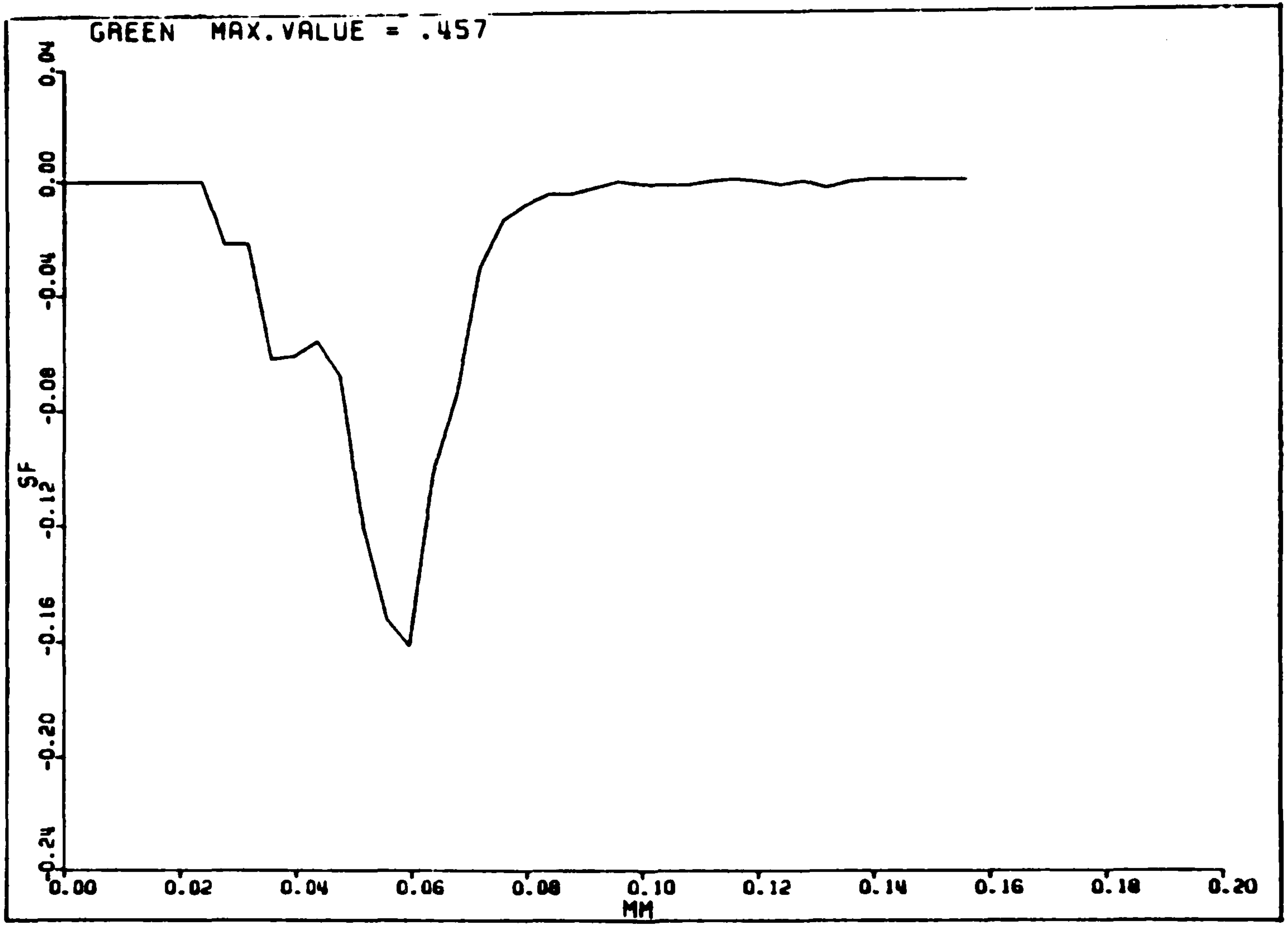
MM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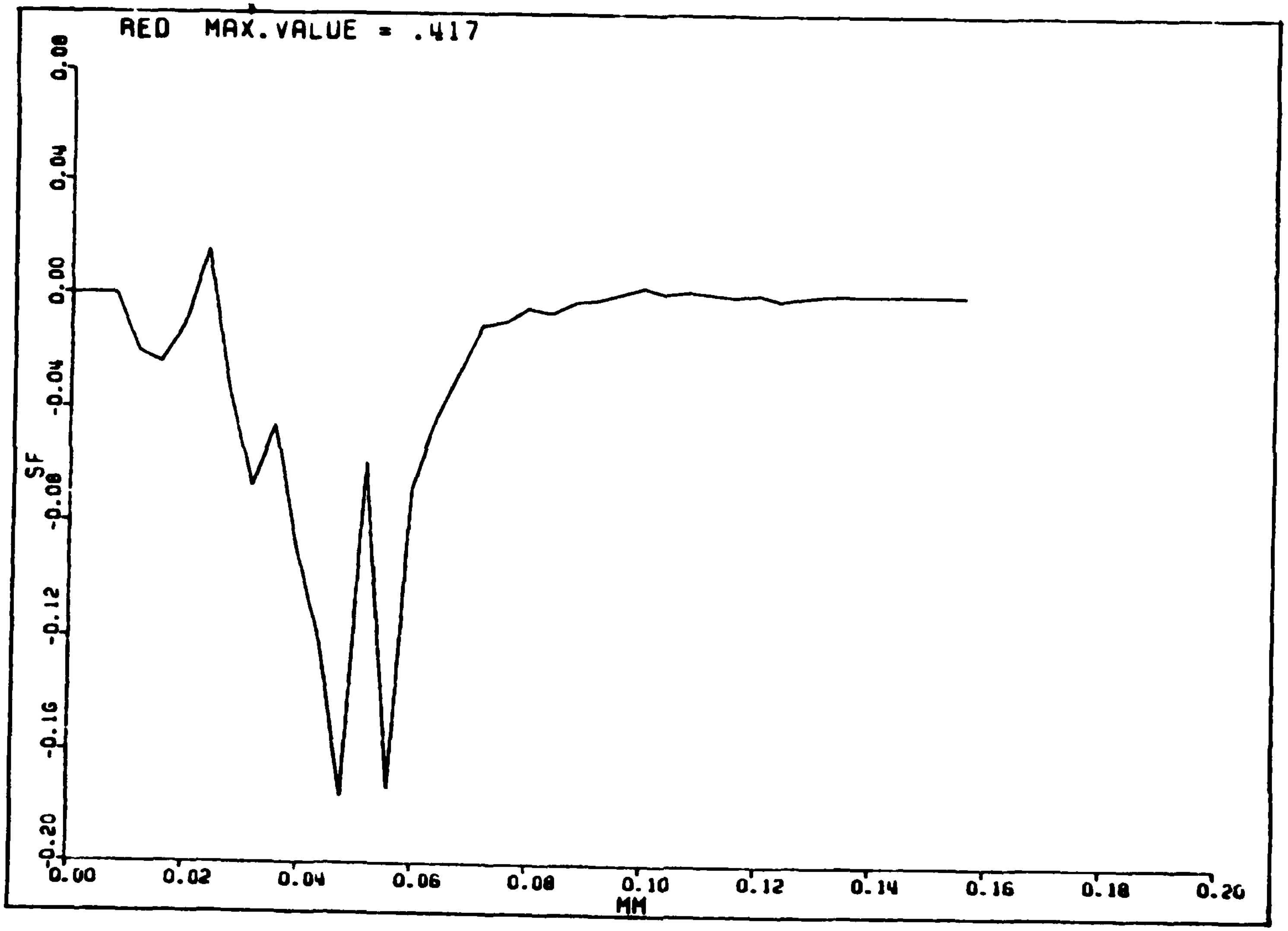

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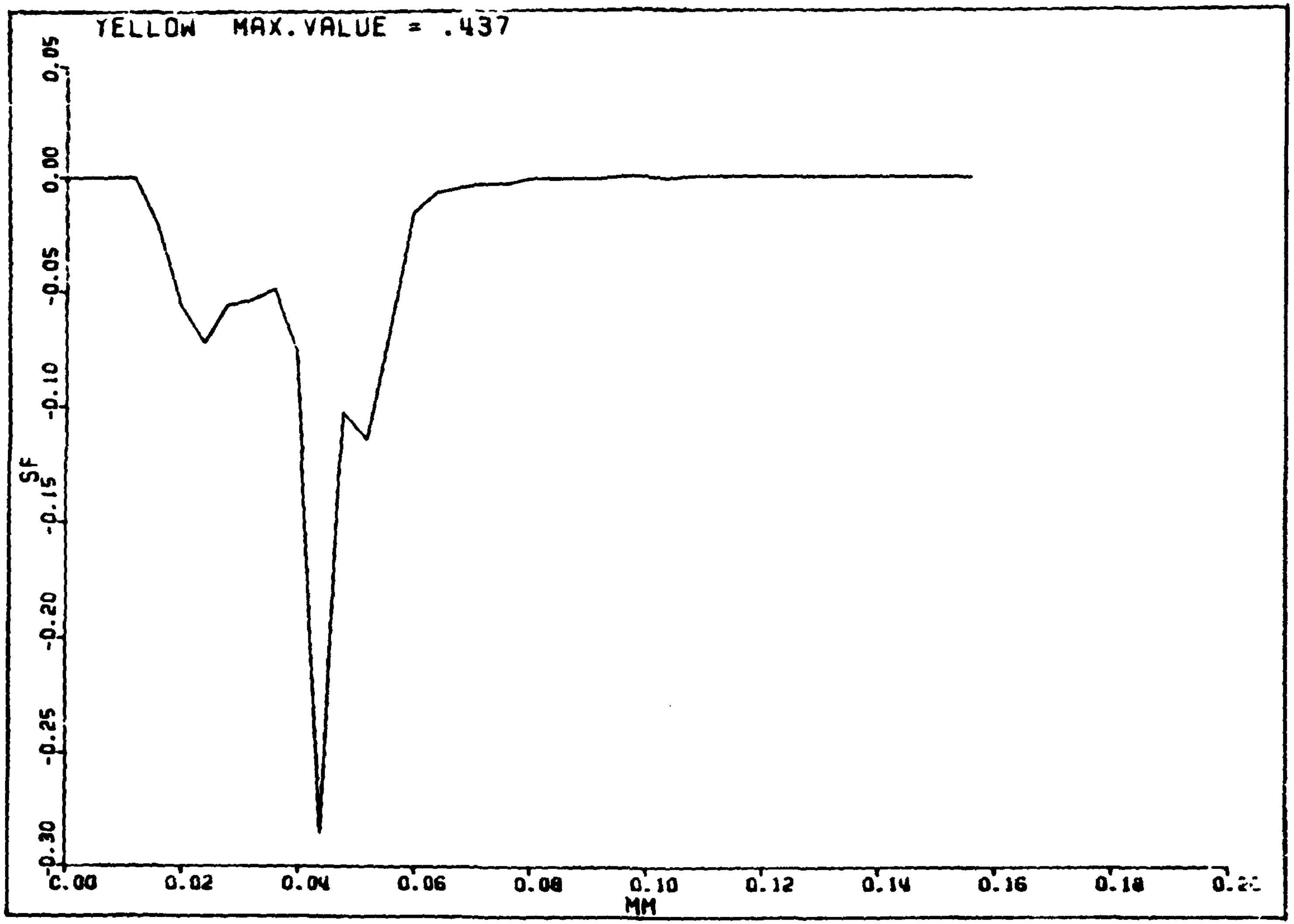

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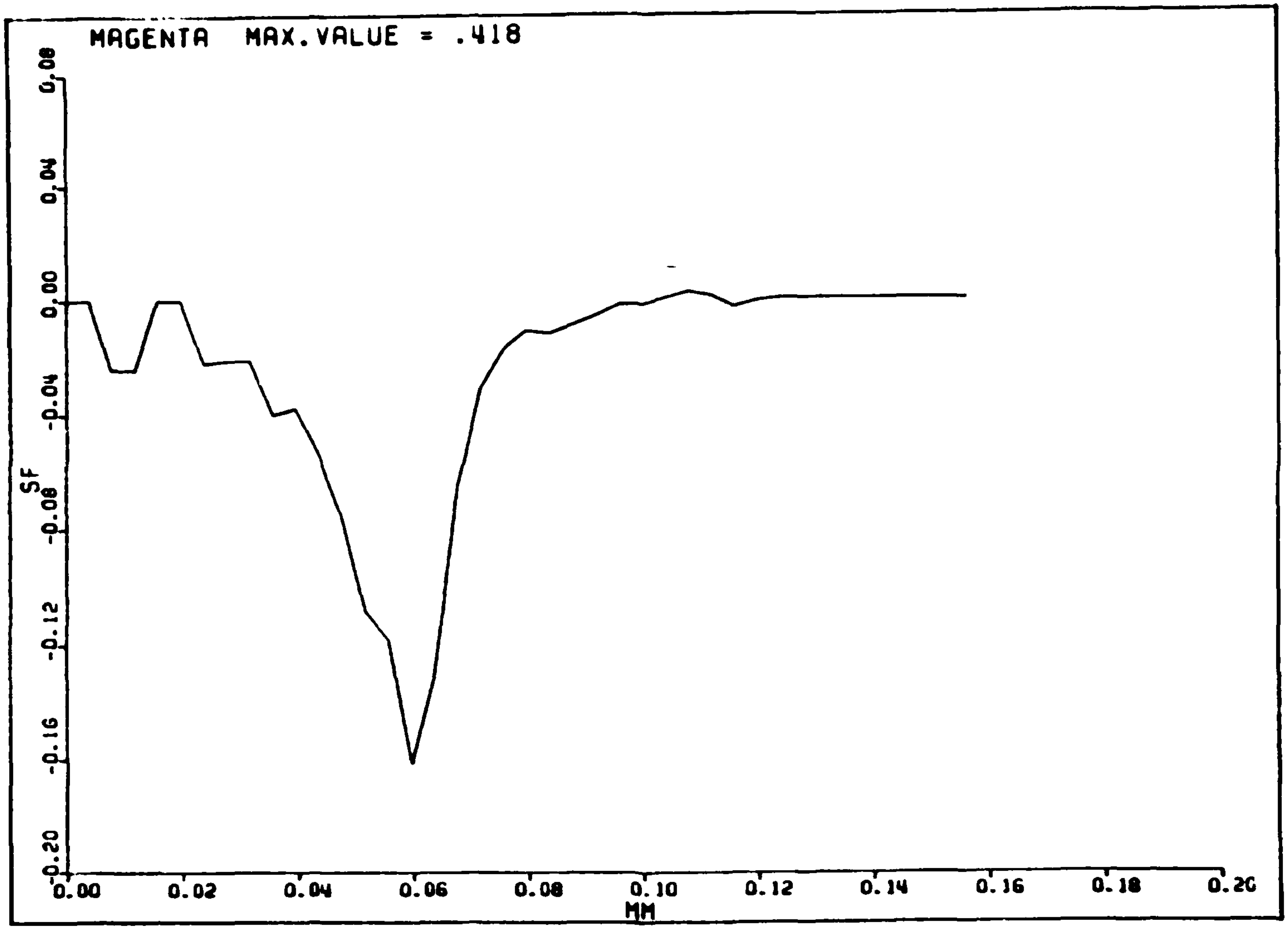
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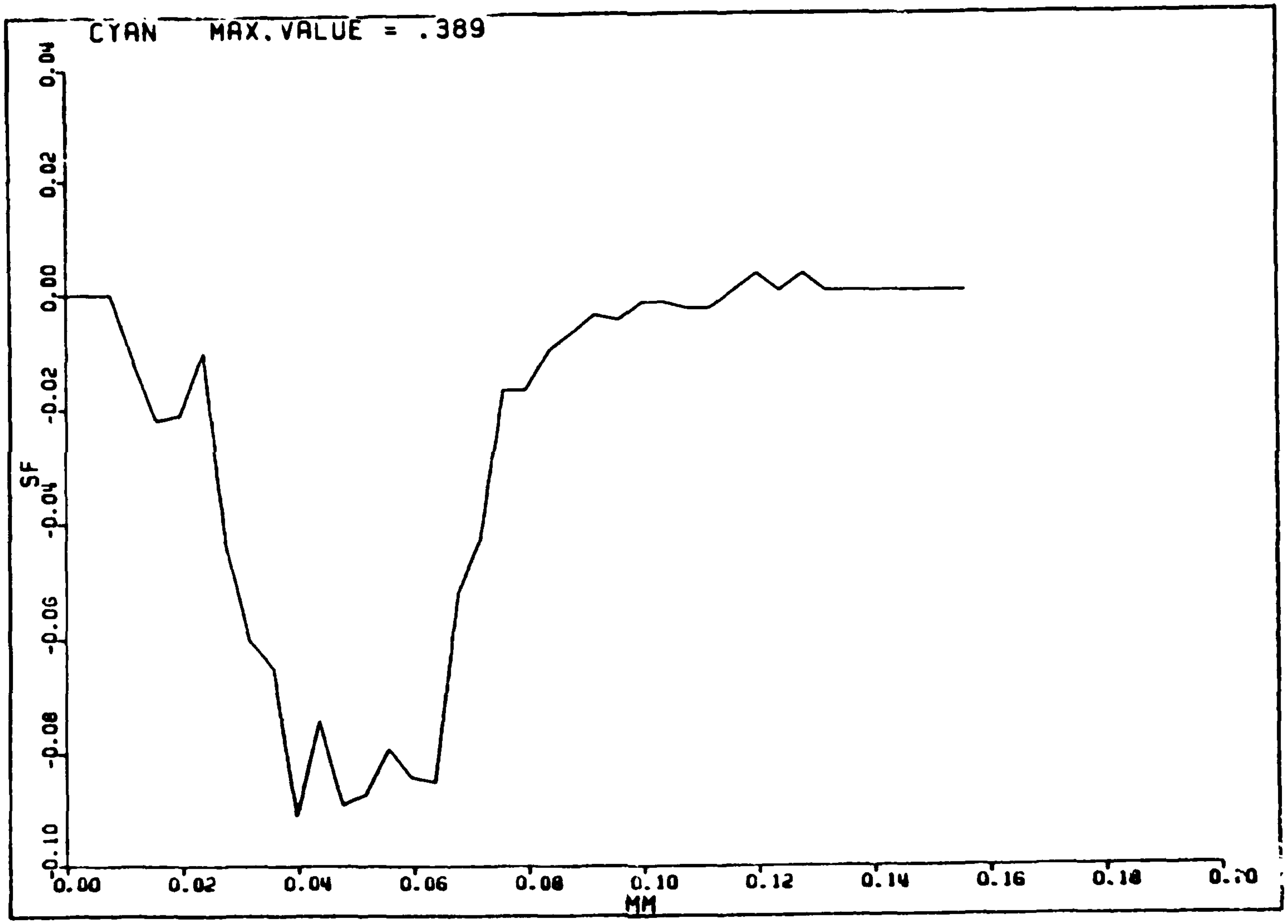

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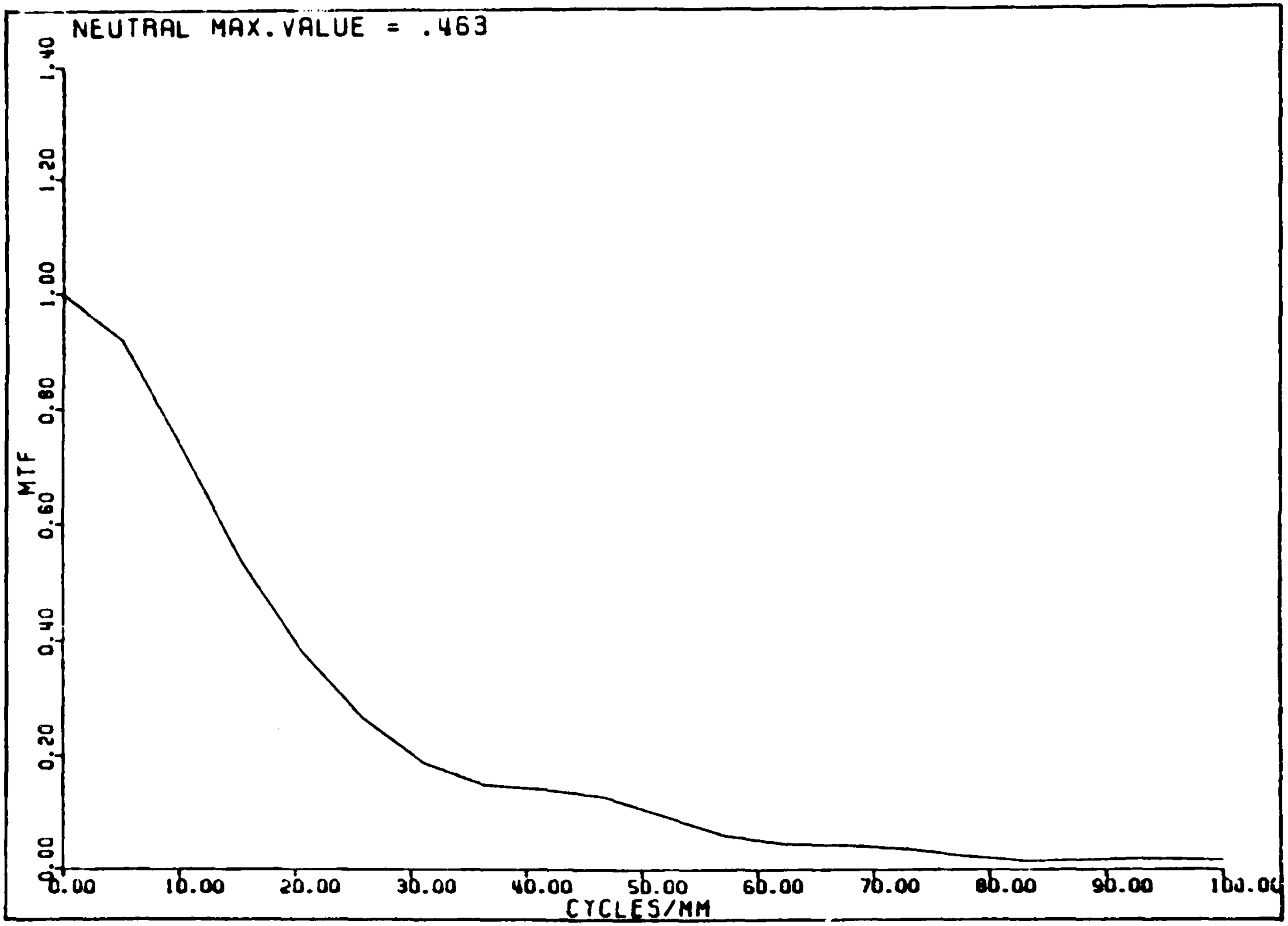
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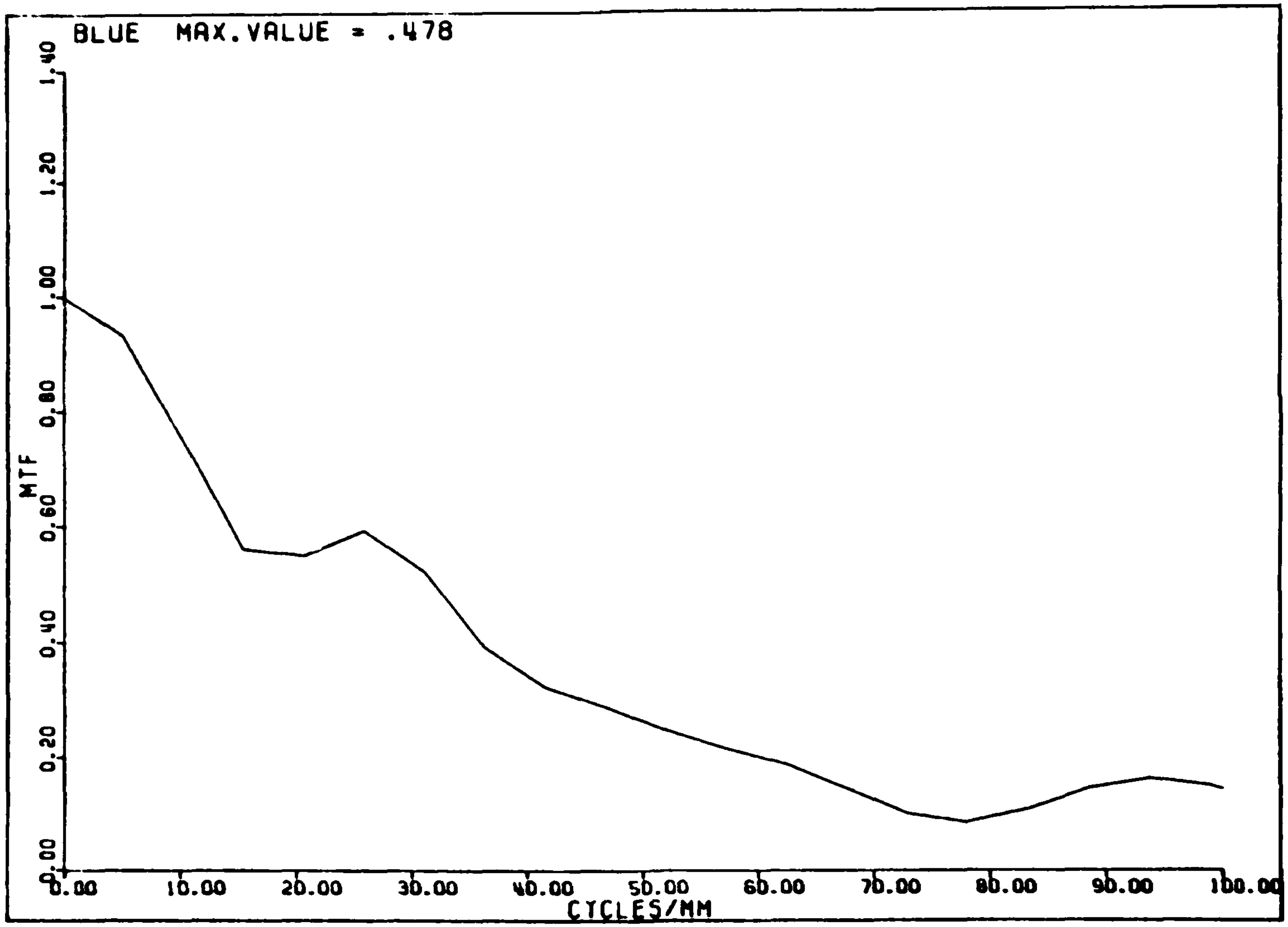
CYCLES/MM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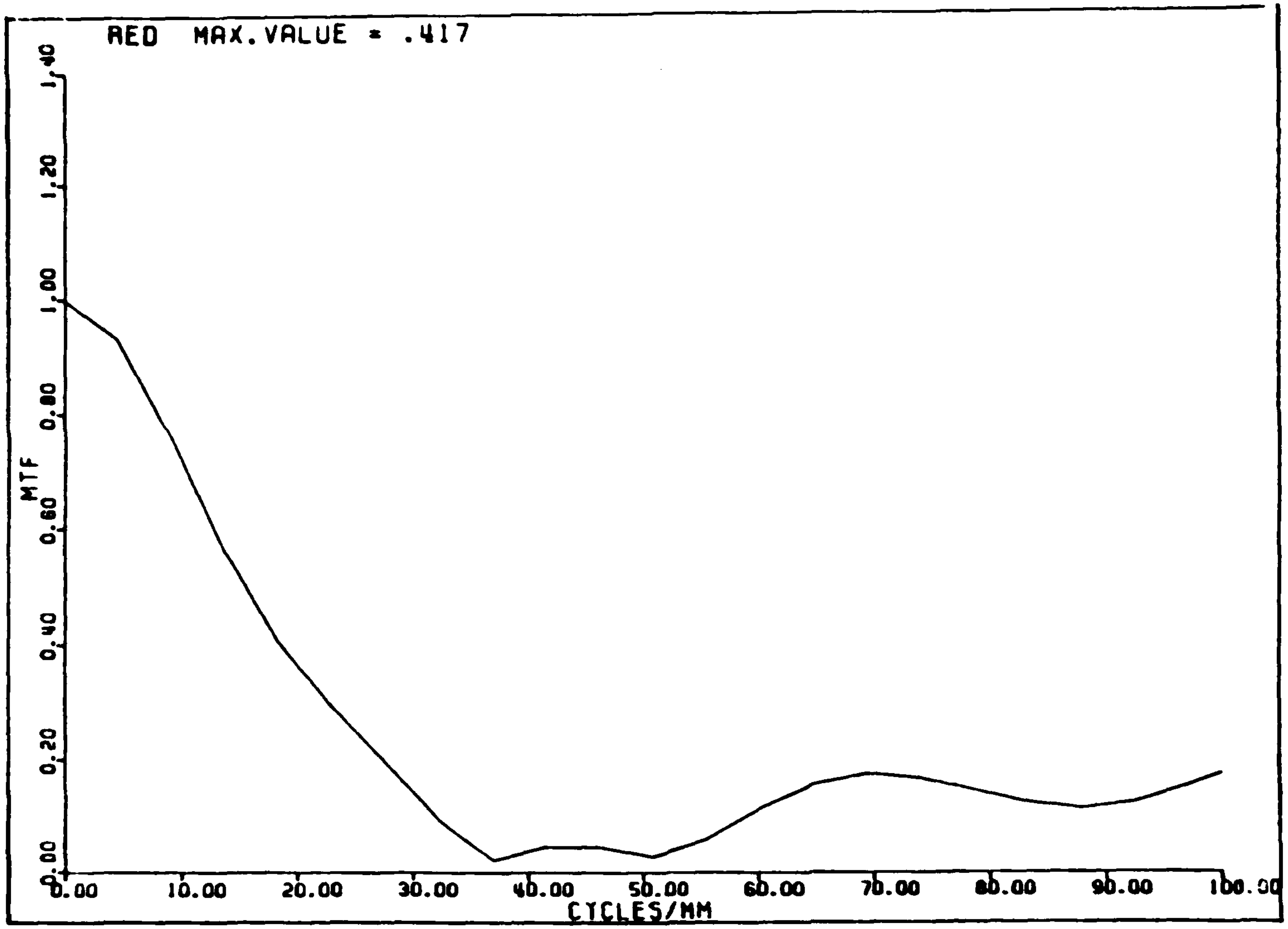
CYCLES/MM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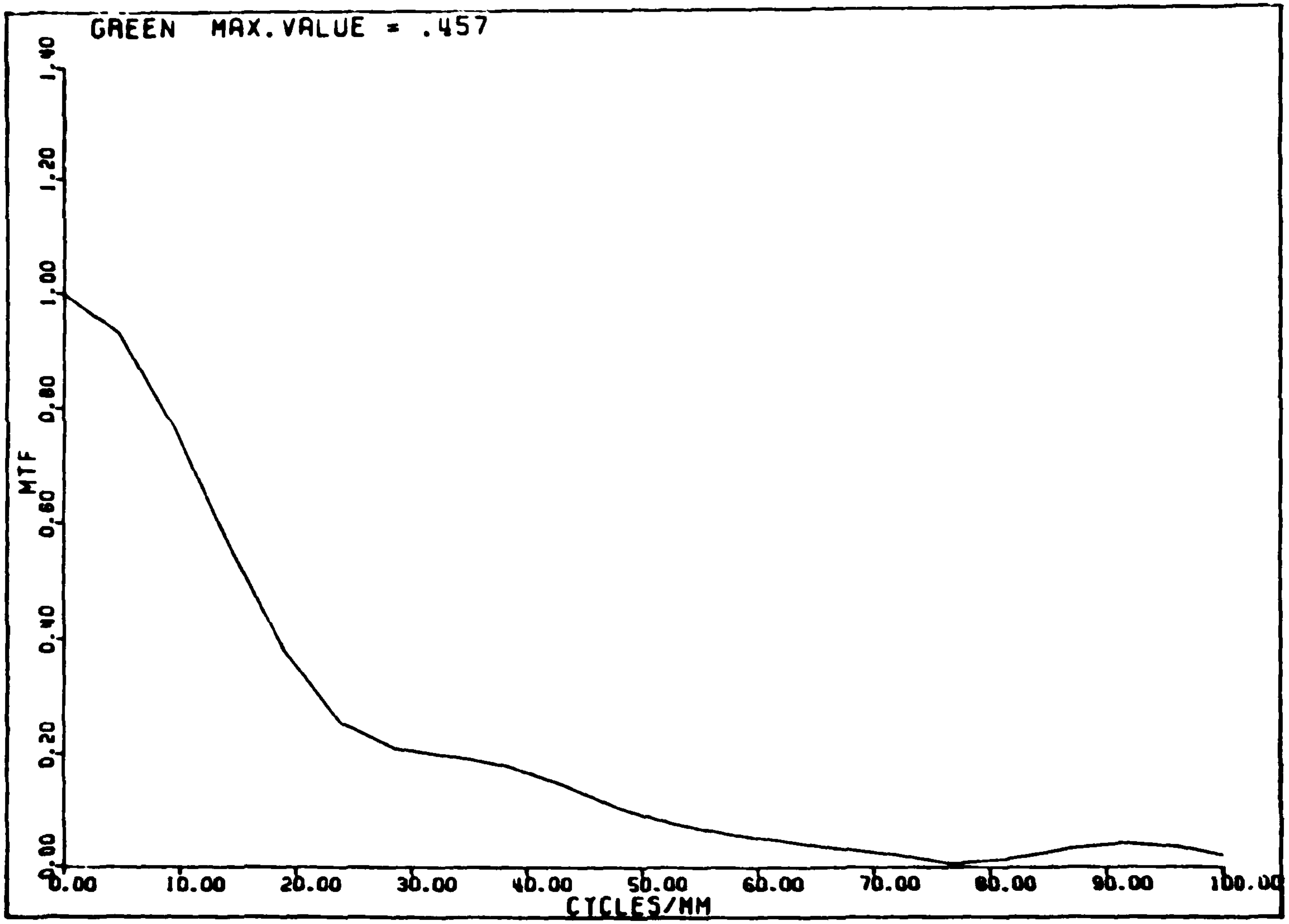
CYCLES/MM



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60.00
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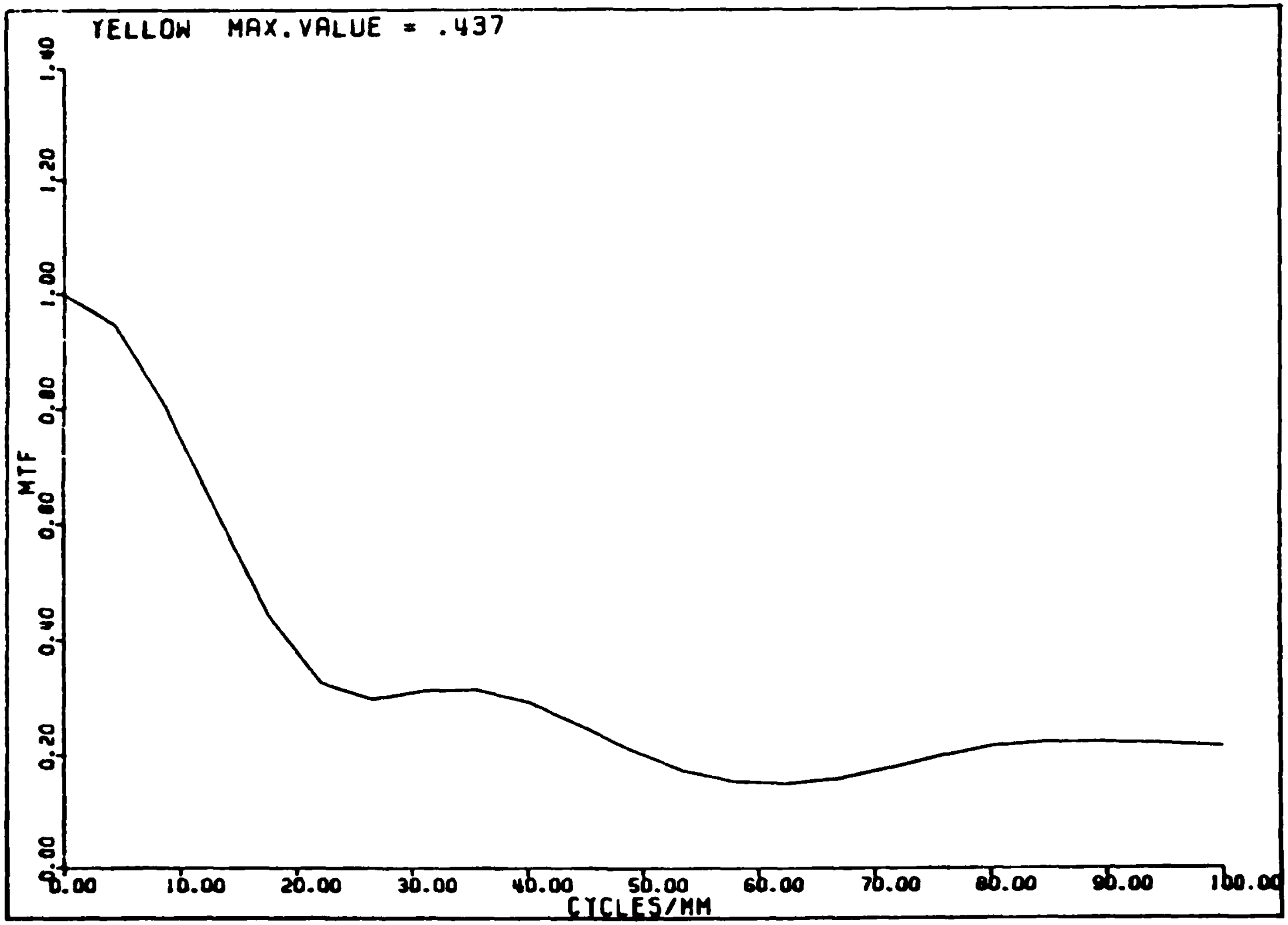
90.00
100.00
CYCLES/MM


YELLOW MAX.VALUE = .437
MTF
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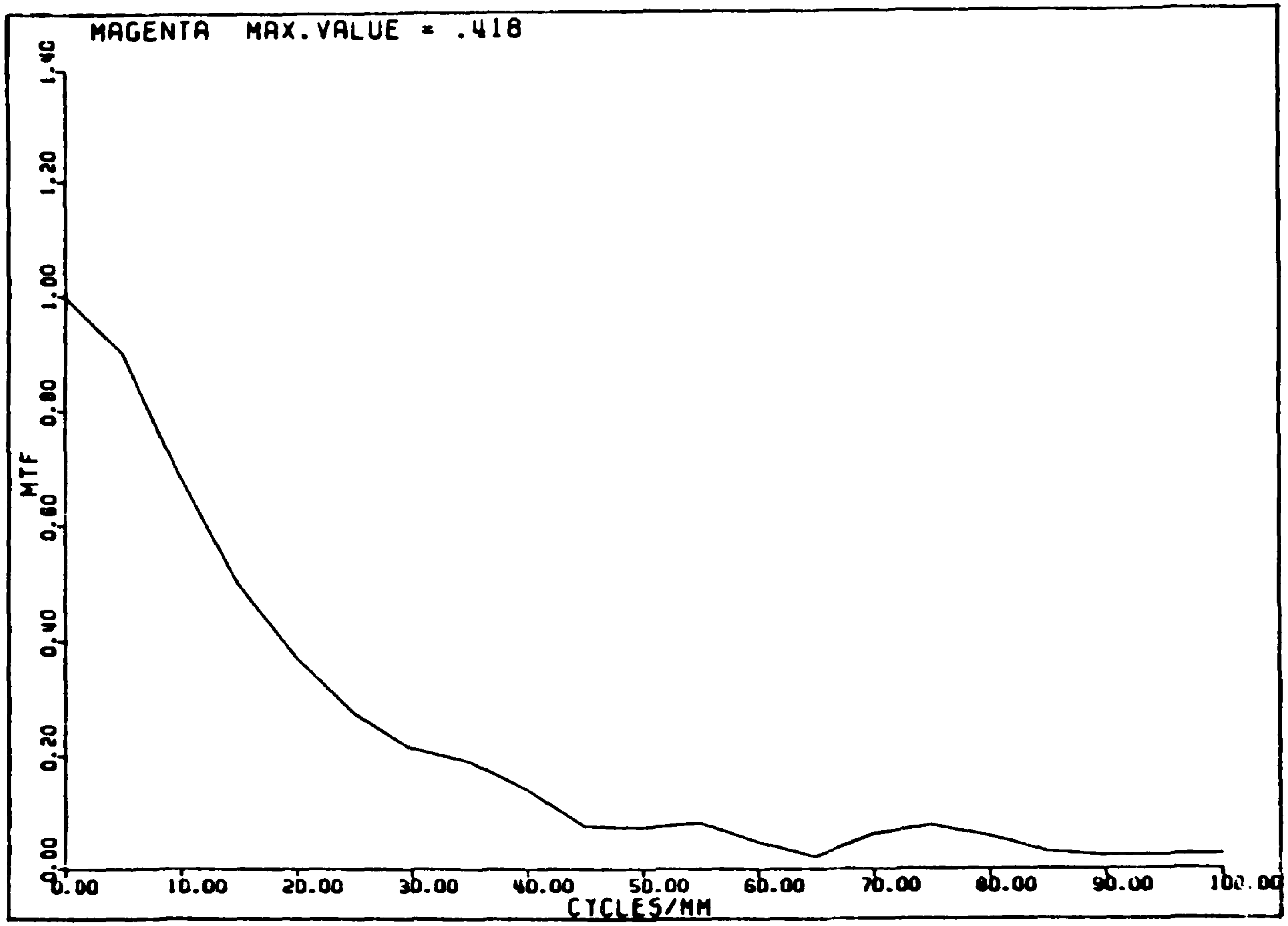
0.40
0.60
0.80
1.00
1.20
1.40
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM


MAGENTA MAX. VALUE = .418
MTF
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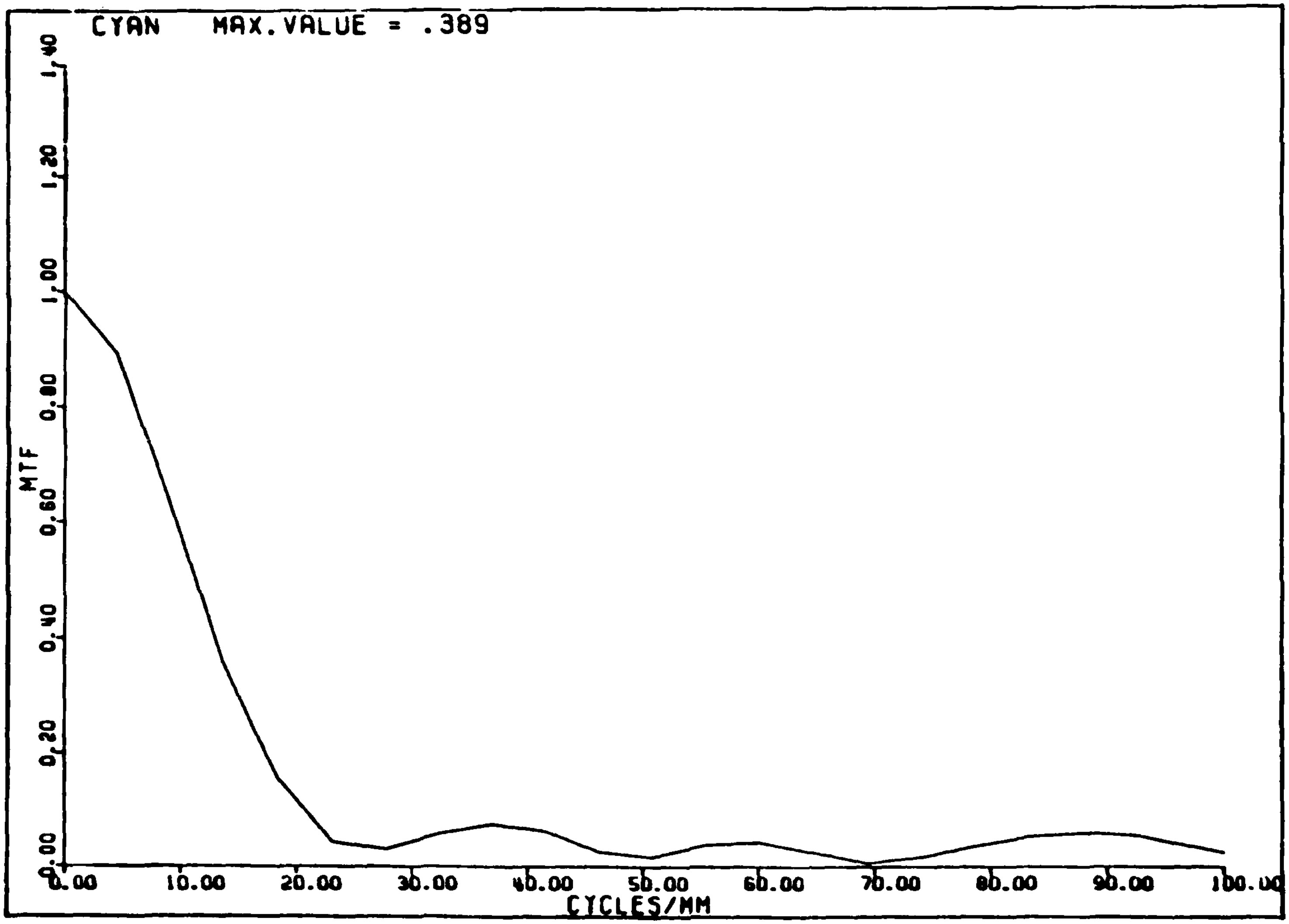
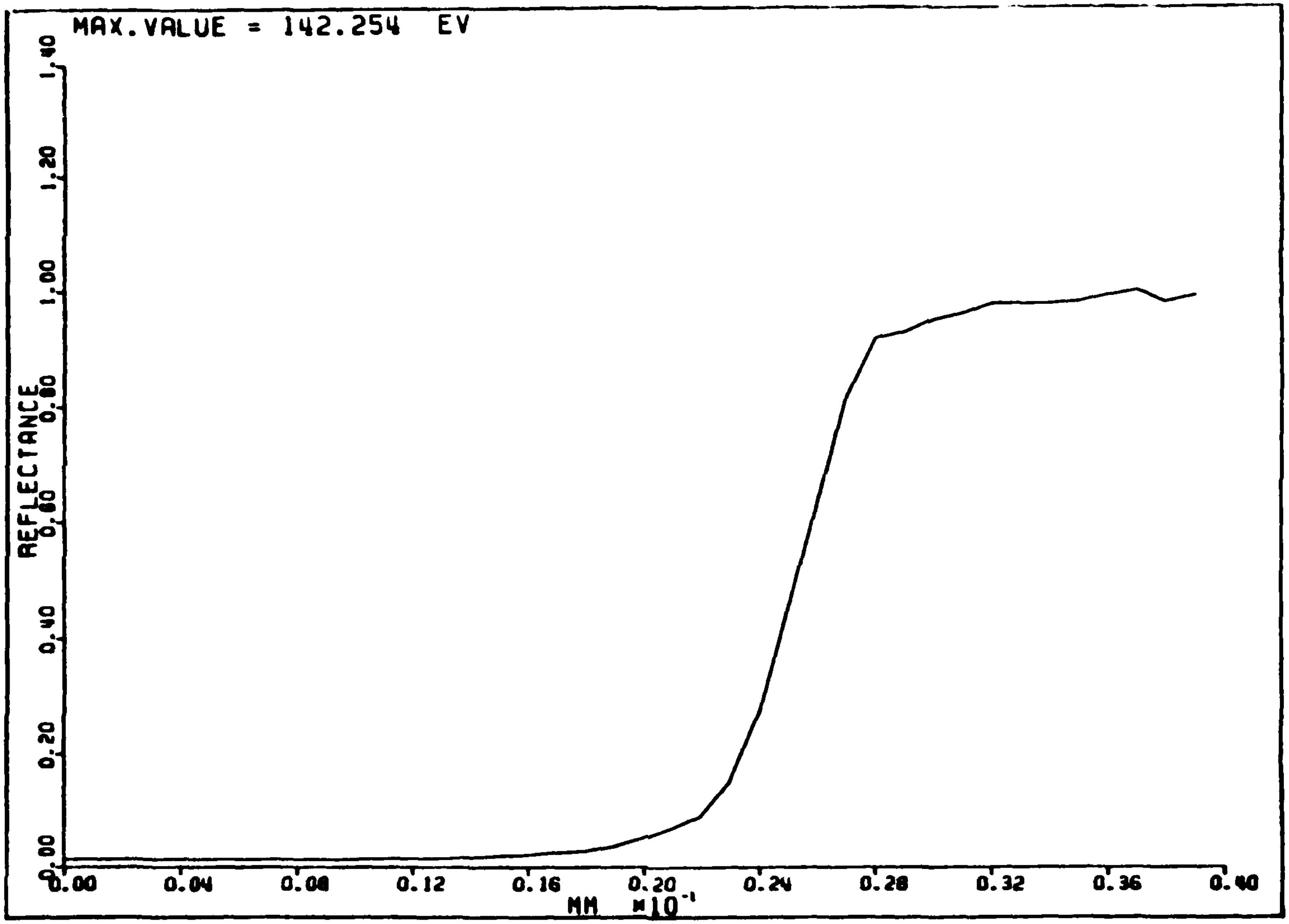
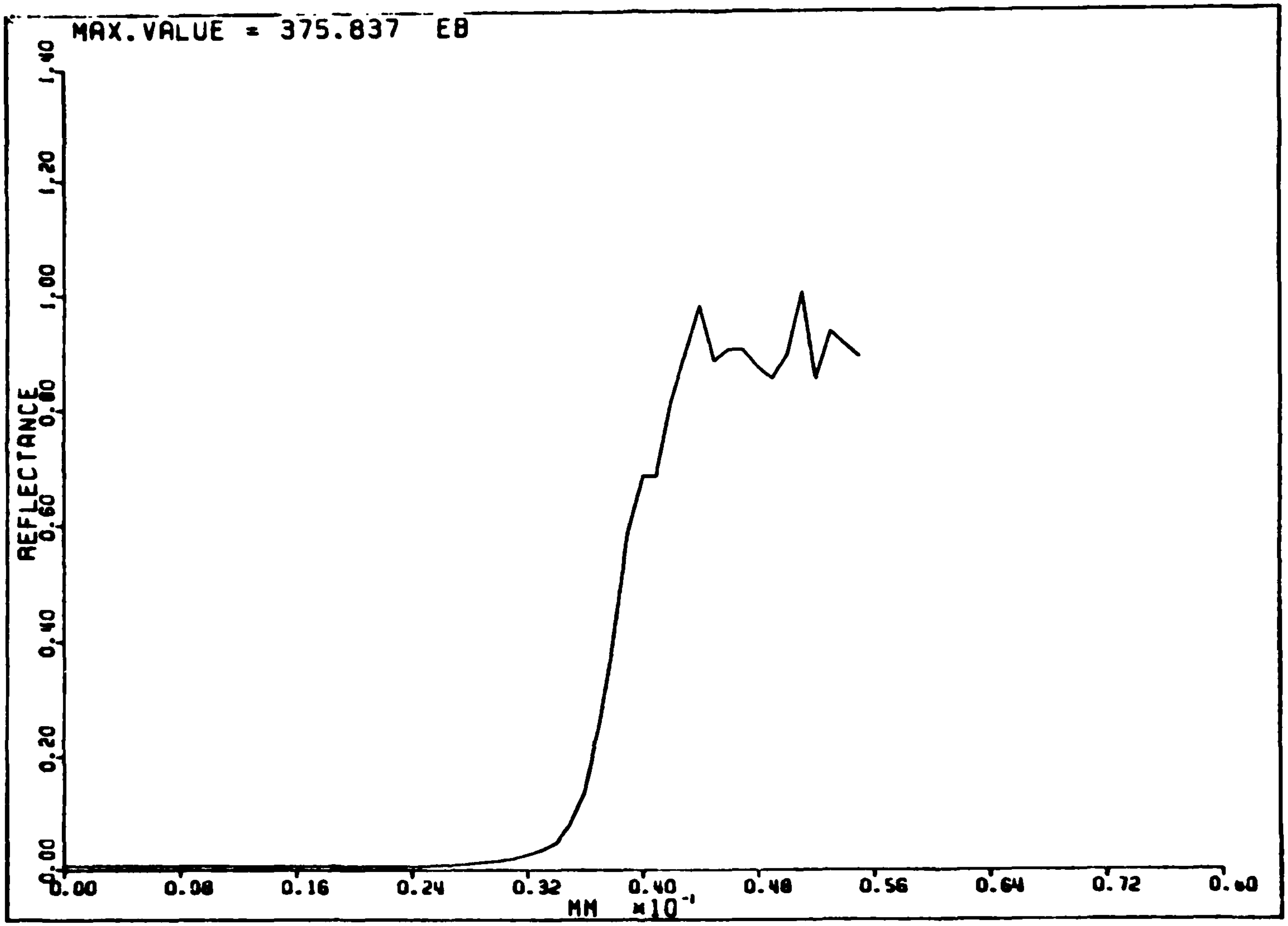
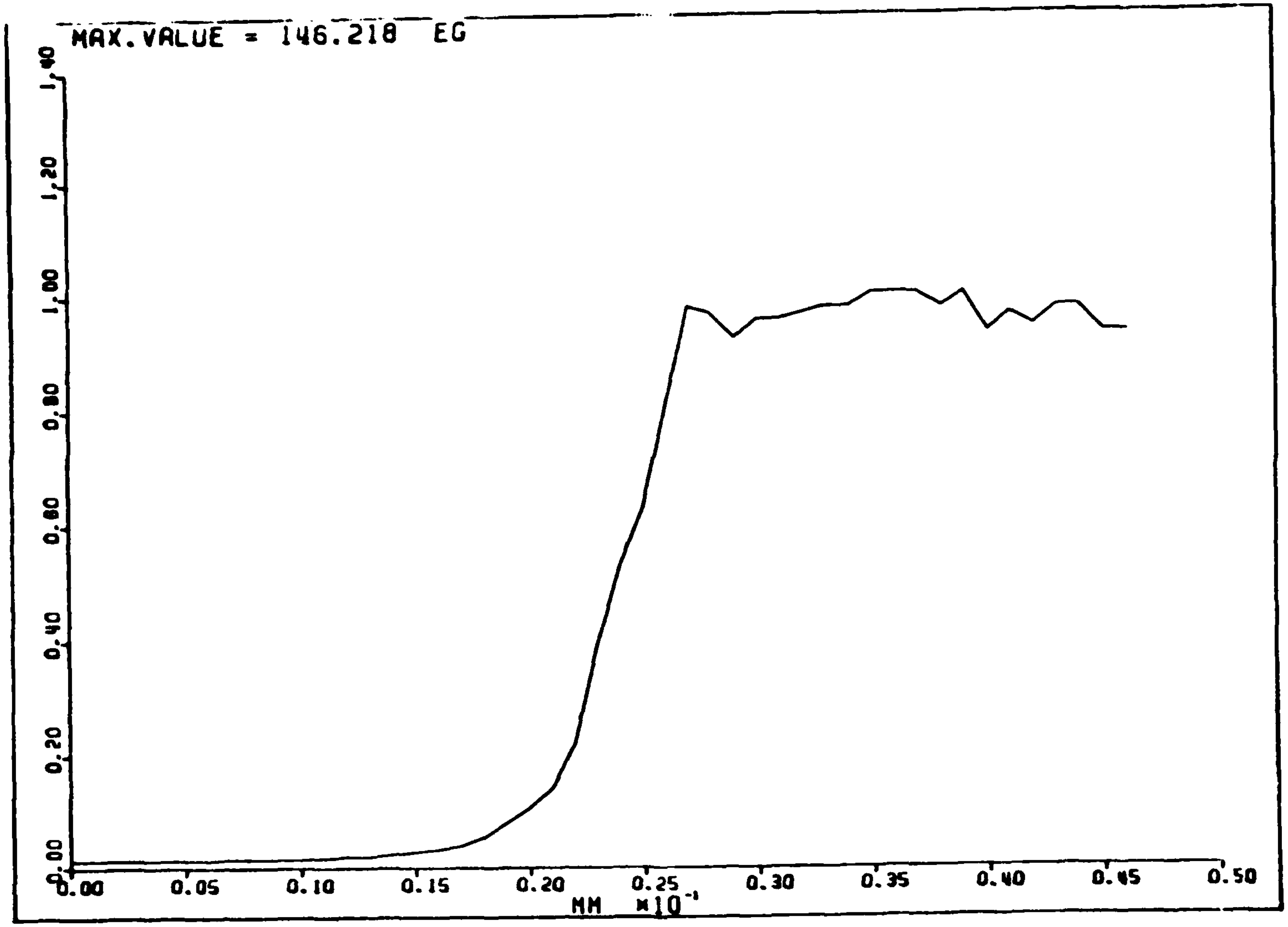
0.40
0.60
0.80
1.00
1.20
1.40
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM

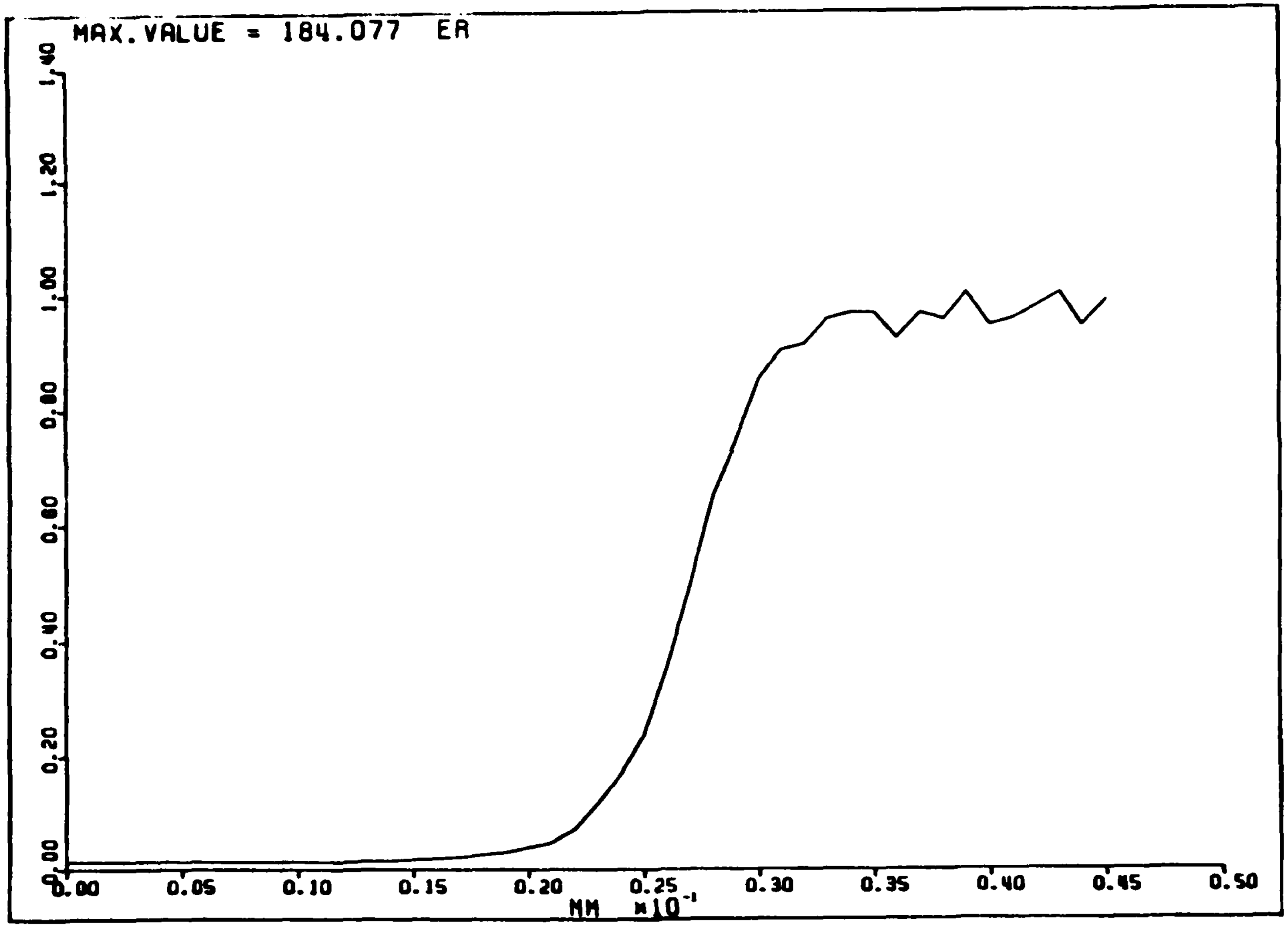


CYAN MAX.VALUE = .389
MTF
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM

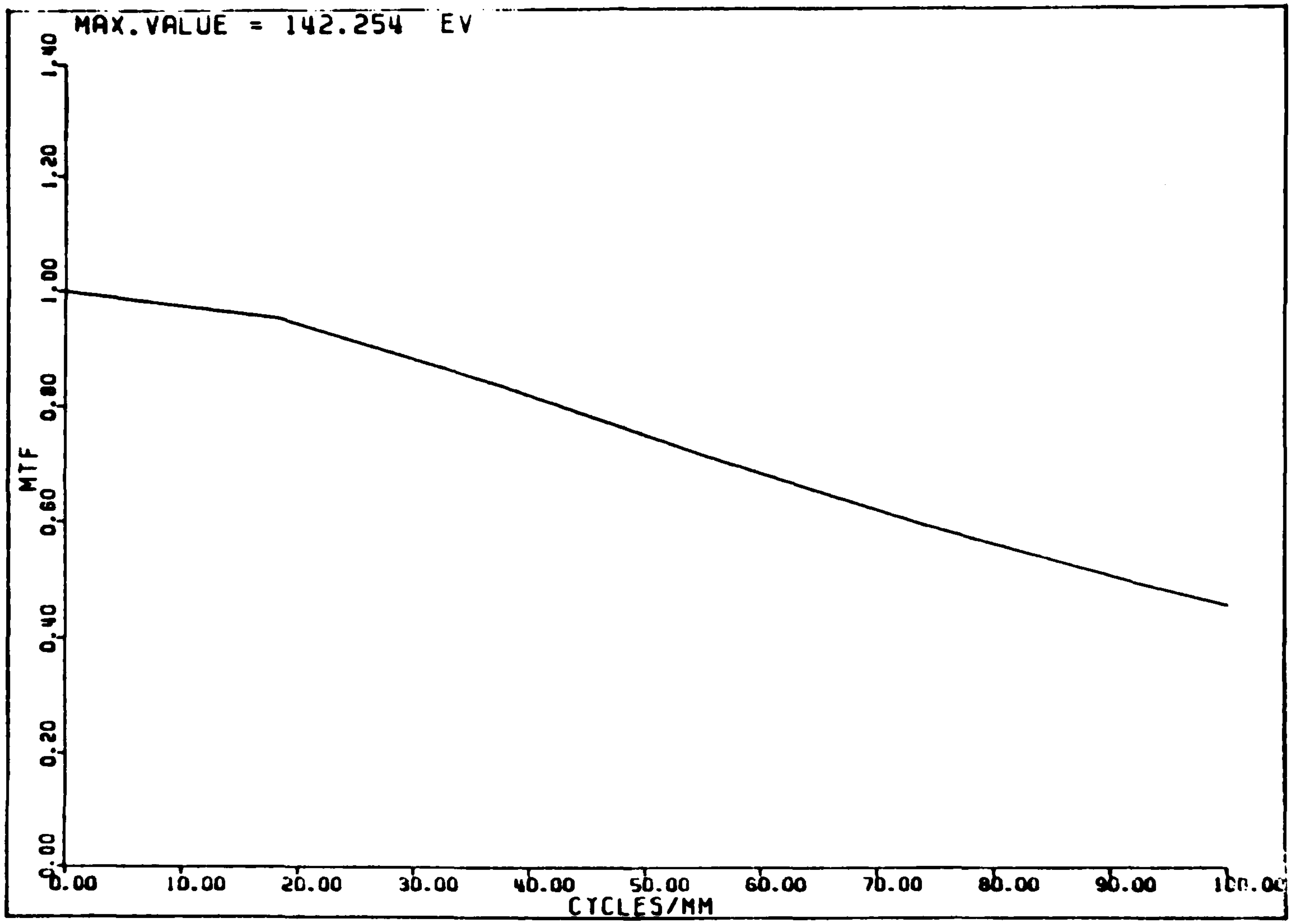

MAX. VALUE = 142.254 EV
REFLECTANCE
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
0.40
MM *10⁻¹


MAX.VALUE = 375.837 EB
REFLECTANCE
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0.00
0.08
0.16
0.24
0.32
0.40
0.48
0.56
0.64
0.72
0.80
MM ×10⁻¹

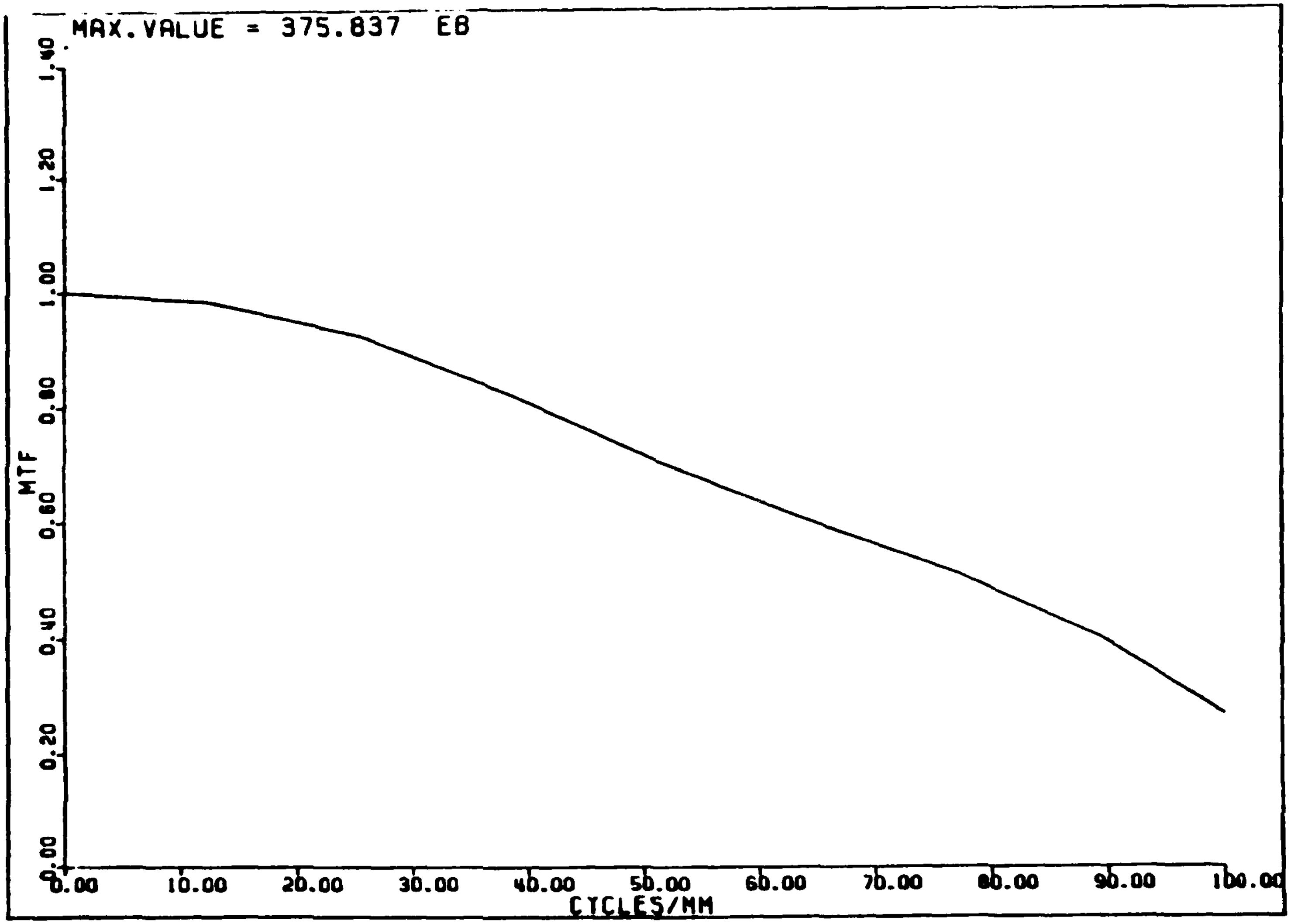

MAX. VALUE = 146.218 EG
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
MM ×10⁻¹



MAX. VALUE = 184.077 ER
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
MM $\times 10^{-1}$



MAX.VALUE = 142.254 EV
MTF
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM


MAX.VALUE = 375.837 EB
MTF
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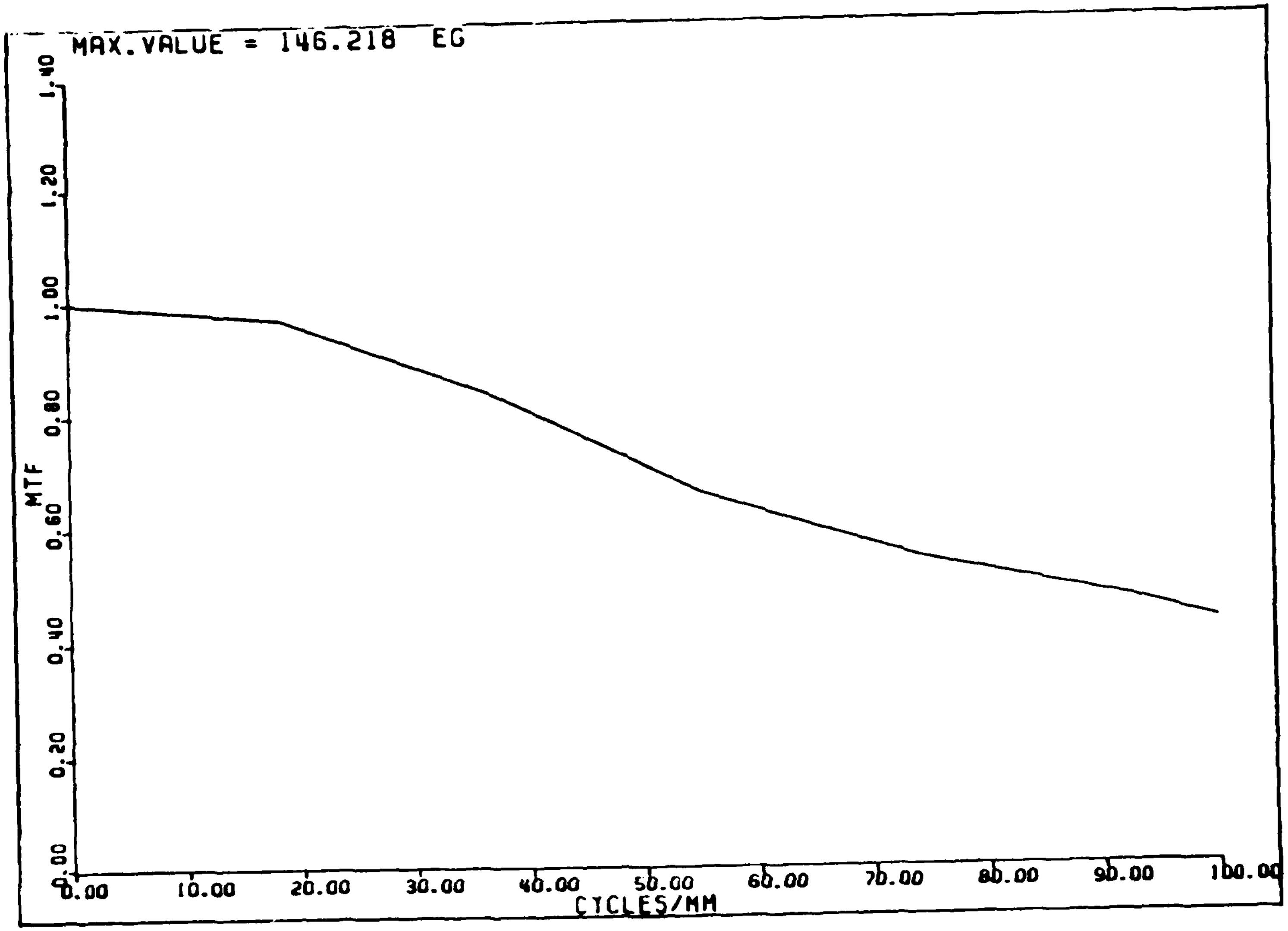
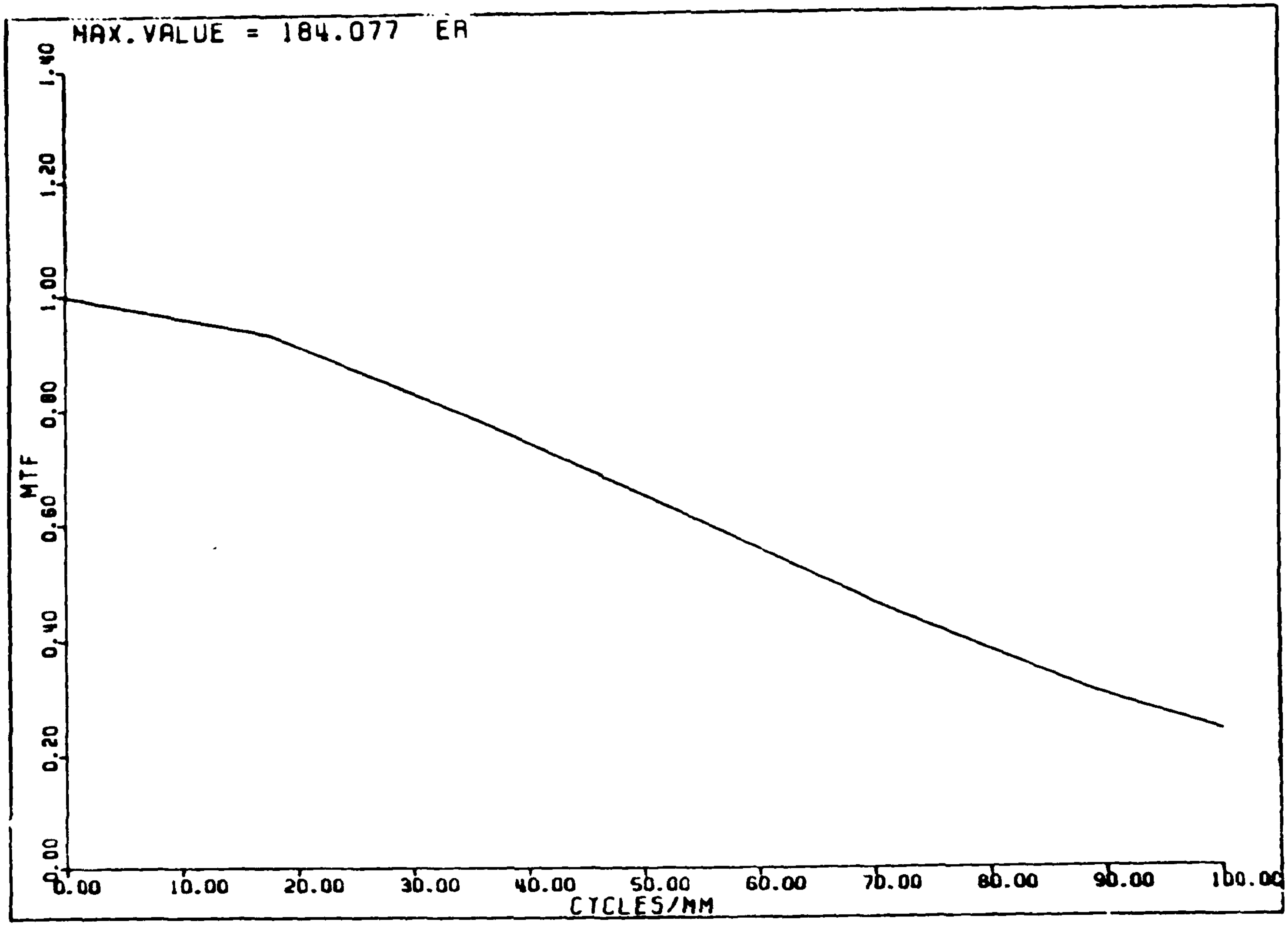
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM


MAX. VALUE = 146.218 EG
MTF
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM


MAX. VALUE = 184.077 EA
MTF
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CYCLES/MM

END

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